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ROOT STUDIES

III. PEAR, GOOSEBERRY AND BLACK CURRANT ROOT SYSTEMS UNDER DIFFERENT SOIL FERTILITY CONDITIONS, WITH SOME OBSERVATIONS ON ROOT STOCK AND SCION EFFECT IN PEARS

By W. S. ROGERS

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INTRODUCTION.

A STRIKING example of improved growth following manuring in the year of planting was found in a plantation at Wrotham Heath, Kent, during the Kent Fruit Soil Survey. The plantation consisted of pears interplanted with gooseberries and black currants. The line of demarcation between the manured and unmanured parts of the plantation was so sharp, and the contrast so great, that it was decided to make a study of the root systems produced under these manured and unmanured conditions by excavating a number of trees and bushes.

The comparisons available were : (a) the root systems of pears, gooseberries, and black currants on similar soil, (b) pears, gooseberries, and black currants manured and unmanured, (c) Dr. Jules pear on seedling pear and on Angers quince stocks, both manured, and (d) Dr. Jules pear and Conference pear, both on Angers quince stock. For purposes of convenience the following arrangement of sections has been adopted.

- I. Method of working.
- II. Material and Location.
- III. The Pear root systems.
 - (a) General characteristics.
 - (b) Manurial effect.
 - (c) Rootstock effect.
 - (d) Variety effect.
- IV. The Gooseberry root systems.
 - (a) General characteristics.
 - (b) Manurial effect.
- V. The Black Currant root systems.
 - (a) General characteristics.
 - (b) Manurial effect.
- VI. Summary.

I. METHOD OF WORKING.

The method of excavation was a further development of that used for the study of apple roots at East Malling (1 and 2). A trench was dug beyond the region of the roots, and this was then worked sideways in "steps" of 50 cm.* (about 20 inches) across the whole root area. In this instance the roots of a tree and several bushes were exposed in the trench at the same time. The soil was gently worked away from the trench face with a small hand fork. As each root was uncovered, it was drawn on a plan, and its depth in centimetres was written beside it. The roots were cut off at the boundaries of every half-metre square, and each root had a zinc label wired on to it on which the identification letters of the root, and the letter and number of the block from which it came, were scratched. Each square was subdivided into three depths, 0-30 cm.,* 30-100 cm. and deeper than 100 cm. Immediately they were cut off, the roots were washed in a bucket of water, hung up to drain, and weighed on a spring balance while the surface was just moist. Thus the total weight of root in each region of soil was obtained.

The roots were brought back to the Research Station for reconstruction of the root systems in their original relative positions, by means of the plan, from the labelled roots. The whole root system could then be observed and photographed. This was carried out with three pear trees and two gooseberry bushes.

II. MATERIAL AND LOCATION.

The trees and bushes excavated were as follows.

Good growth portion (manured with fifty loads of farmyard manure per acre in year of planting).

One Dr. Jules pear on seedling pear stock.

One Conference pear on Angers Quince stock. (Quince A.)

One Dr. Jules pear on Angers Quince stock.

Three Seabrook's black currants.

Two Whitesmith gooseberries.

Bad growth portion (not manured in year of planting).

One Dr. Jules pear on seedling pear stock.

One Conference pear on Angers Quince stock.

Six Seabrook's black currants.

Two Whitesmith gooseberries.

The trees and bushes were all eight years old when excavated (February, 1930).

The pear trees were planted with 10 feet spacing in rows 10 feet apart. Gooseberry bushes occupied the spaces between the pear trees in the row, and there was a row of black currant bushes 5 feet apart running midway between

* 100 cm. = 3.28 ft.

the pear rows. Thus the trees and bushes formed a 5-foot square planting over the whole area.

Soil.

This plantation has a gentle downward slope towards the North and was found to be downwash of Folkestone Sands over Sandgate Beds. The soil is of very sandy nature. It was named the "Lowlands Series".

A general description of the soil profile is as follows: About 20 cm. dark sandy top soil, then loose sandy material lighter in colour to about 100 cm., becoming harder and with some flints to about 150 cm. From 150 cm. greenish admixtures (of Sandgate Beds material) were visible, and the soil became distinctly wetter at about 240 cm. (about 8 ft.). Standing water was found at 250 cm. (during February, 1930). There was a rather greater depth of loose subsoil below the unmanured trees than below the manured trees.

Fuller details and analyses are available, but are omitted on account of the need for brevity.

Validity of Results.

Excavation work is costly so only a small number of trees could be excavated, and the numbers available in the various comparisons are therefore small. In Tables I and II each figure refers to only one tree. While these trees were carefully chosen as representative of a number of similar trees in the orchard, no valid estimate of the amount of variation due to position in the field or to natural variability in the material can be given. However, in most of the cases under discussion the conclusions drawn from the trees of one variety can be checked by the results given by the other, and remarkably close agreement has been found.

Two gooseberry bushes of each treatment were excavated, and the results from each bush are given. In the case of the black currants, the mean of two unmanured bushes and the mean of three manured bushes is given, as full root records were not obtained on the whole nine bushes excavated.

Many of the qualitative observations are quite evident from the photographs and notes. Some of the quantitative differences are also so large that little doubt concerning their validity can exist. In other cases differences are smaller but very suggestive, but provided the drawbacks inherent in such a piece of work are borne in mind, the comparisons may give some new and interesting preliminary information in a comparatively unexplored field.

III. THE PEAR ROOT SYSTEMS.

(a) GENERAL CHARACTERISTICS.

The general appearance of the root systems of Dr. Jules on seedling pear root-stock can be seen in Plates II and III. The difference in size between the manured

and unmanured trees is obvious, but in both trees the downward habit of many main roots is also evident. None of these roots is a true tap root. There are a few fairly shallow roots spreading out horizontally. The main descending roots followed a fairly straight course to a depth of about 100 cm. (3·28 ft.) but on coming to the harder layer they were evidently checked, and some stopped or turned horizontally (Plate I). Others worked their way round the stones and continued in a downward direction to a maximum depth of 337 cm. (11 ft.). These deepest roots were very thin below about 250 cm. from the surface and were probably not more than a year old. They seemed to be quite alive, however, although they were below the water table when excavated. It would seem evident that these deep roots kept the trees supplied with water when the sandy top soil dried out in summer.

The contrast between the seedling pear and the Angers quince root systems is dealt with later.

The seedling pear roots were tough and quite strong. The larger roots had a dark brown bark, with a dark reticulation along it. The smaller roots were lighter brown in colour. White succulent ends were noted on some of the roots, which were apparently in active growth, although the branches were dormant. One white end, 6 cm. long, was noted on P₂ (Conference on Quince) at a depth of 150 cm. on February 14th.

(b) MANURIAL EFFECT.

The great increase in size of the manured Dr. Jules pear tree over the unmanured tree is visible in Plates II and III.

The amount and extent of root and branch are shown in Table I.

Comparing the unmanured and manured Dr. Jules on seedling pear trees (P₁ and P₃), it will be seen that the manured tree was much heavier, taller and more spreading than the unmanured tree. The total weight (of roots and stems, in the dormant state) of the unmanured tree was 4,837 gm., and of the manured tree 13,546 gm., 2·8 times as much.

The variety Conference on Quince A shows a similar contrast. Though the increase in height and spread of the manured tree over the unmanured tree is not quite so great as in the case of the Dr. Jules, the total weight of the manured tree is 2·7 times that of the unmanured tree. The actual figures are : manured, 7,294 gm. and unmanured, 2,659 gm.

Root Spread.

In every case the root spread greatly exceeds the branch spread. In three cases it is about three times as great, in one case it is 2·6 times, and in one case 7·3 times as great. These excavations show clearly that these roots by no means form a reflection of the branches.

TABLE I.

Effect of Manuring, Rootstock, and Variety on Root and Stem growth of Pears.

Variety	Dr. Jules.		Conference.		Dr. Jules.
Rootstock	on Seedling Pear.		on Quince A.		on Quince A.
Treatment	not manured.	manured.*	not manured.	manured.*	manured.*
Tree No.	Pr.	P3.	P2.	P4.	P5.
Branch weight, gm.	3,200	9,480	1,890	5,250	4,360
Root weight, gm.	1,637	4,066	869	2,044	1,197
Total weight, Root plus branch, gm.	4,837	13,546	2,659	7,294	5,557
Ratio of stem weight to root weight	1.95	2.33	2.17	2.57	3.64
Maximum branch height, cm. ..	177	253	178	224	216
Maximum root depth, cm. ..	337	314	159	247	240
Mean branch spread, cm. ..	66	135	70	95	93
Mean root spread, cm. ..	480	355	235	290	315
Ratio of root spread to branch spread	7.3	2.6	3.4	3.0	3.4

* The manurial treatment was 50 loads of farmyard manure per acre in year of planting, eight years before these records were taken. (1 load = about 2,000 lb.)

100 cm. = 3.28 ft. 1,000 gm. = 2.2 lb.

Note. Trees Pr and P2 had been pruned before the measurements were made. This must have slightly reduced the figures for branch height, spread and weight. The losses were hardly appreciable, however, owing to the small amount of new growth on the unmanured trees.

A circle drawn with the *height* of the tree as radius would have included very nearly all the roots of these pear trees. As the root plans show (Figs. 1 and 2), the root system is often very asymmetrical, however, and one or two roots may travel on for a considerable distance beyond the main bulk of the root system.

The unmanured trees had a relatively more spreading type of root than the manured trees. This shows well in the comparison of Plates II and III. The sparse "hungry" type of root of the unmanured tree searching on and on through the poor soil can be seen in Plate III which shows the remarkable maximum root spread (5.4 metres) of the unmanured Dr. Jules on seedling pear. The same tendency can be seen in the root plans of the Conference on Quince A (Figs. 1 and 2), though it was not so pronounced in this variety and stock.

The radial root distribution by weight can be shown by a diagram giving the root weight in each 50 cm. square block extending from the surface down to the limit of the root area. This data is given in Appendix A. Owing to the fact that the old and thick roots near the trunk are naturally much heavier than



FIG. 2.

Root plan of Conference pear (P2) on Quince A rootstock, unmanured.

The smaller fibrous roots are omitted.

The figures show the depth of the adjacent root in centimetres. The small circles indicate vertical roots, and the figures beside them the upper and lower limits of the root. The dotted lines indicate branch spread. The plan is ruled in one-metre squares.

the young roots farther away, such a diagram will give a false impression of the root system unless it is clearly remembered that 100 gm. of root round the trunk does not represent ten times as much absorbing capacity as 10 grammes of root further out. A truer measure of the absorbing area is obtained by removing the fine roots below 1 mm. diameter and weighing them separately. This was not possible in this particular piece of work, but in a previous excavation where this separate weighing of the fine root was carried out (1) it was found that the fine root was fairly evenly distributed over the whole root system, and only about 10 per cent of it occurred in the metre square surrounding the trunk of a ten-year-old apple tree.

It will be noted, however, that the unmanured Dr. Jules on seedling pear (P1) had 38.1 per cent of its root weight outside the one metre square surrounding the trunk, while the corresponding manured tree (P3) had only 29.8 per cent of its root weight outside the one metre square. Similarly the unmanured Conference on Quince A (P2) had 32.6 per cent of its root weight outside the one metre square, while the figure for the corresponding manured tree (P4) was 20.8. Hence it can be concluded that this manuring has tended to make a root system which, while it is actually greater, is relatively more compact than an unmanured root system.

Depth of Root.

The figures for maximum depth of root given in Table I, while they illustrate the remarkable depth to which the roots penetrated, do not give a very good picture of the effect of the different treatments, since they only refer to one or two outstandingly deep roots. It will be noted that the unmanured Dr. Jules on seedling pear (P1) descending to 337 cm., penetrated a little deeper than the manured tree (P3); while the unmanured Conference on Quince A only penetrated to 159 cm., 92 cm. less than the corresponding manured tree.

Table II shows the percentage of root weight in the different strata of soil. Here again the influence of a few large roots around the trunk tends to swamp the distribution figures; but a fair idea of the depth distribution can be gained if that point is kept in mind. Both in the case of the Dr. Jules and the Conference the manured tree has a higher percentage of root weight in the top 30 cm. (1 ft.) of soil than the unmanured tree, and the manured trees also have a lower percentage of root below one metre than the unmanured trees. The fact that the unmanured and manured Dr. Jules trees on seedling pear have 29.1 per cent and 20.3 per cent respectively of their total root weight below one metre from the surface emphasizes the very considerable depth at which the tree was feeding. It appears from the figures, however, that the manure applied to the surface has had the effect of keeping the root system relatively shallower than it would have gone without the manure.



Roots of Dr. Jules on seedling pear showing (left) vigorous vertically descending roots and absence of a tap root, and (right) checking and turning of roots on reaching a hard layer at about 100 cm. deep.

PLATE II.



Eight-year-old Dr. Jules pear on seedling pear rootstock, manured with fifty loads farmyard manure in year of planting. The root system is reconstructed in its original relative position.

The measure is marked in metres and tenths. 1 metre = 3.28 feet.

PLATE III.



Eight-year-old Dr. Jules pear on seedling pear rootstock *not* manured in year of planting. The sparse spreading type of root produced in poor soil can be seen. Compare with Plate II.

The root system is reconstructed in its original relative position. The measure is marked in metres and tenths.



Close view of Dr. Jules pear on Quince A stock, showing horizontal main roots and fine descending roots.

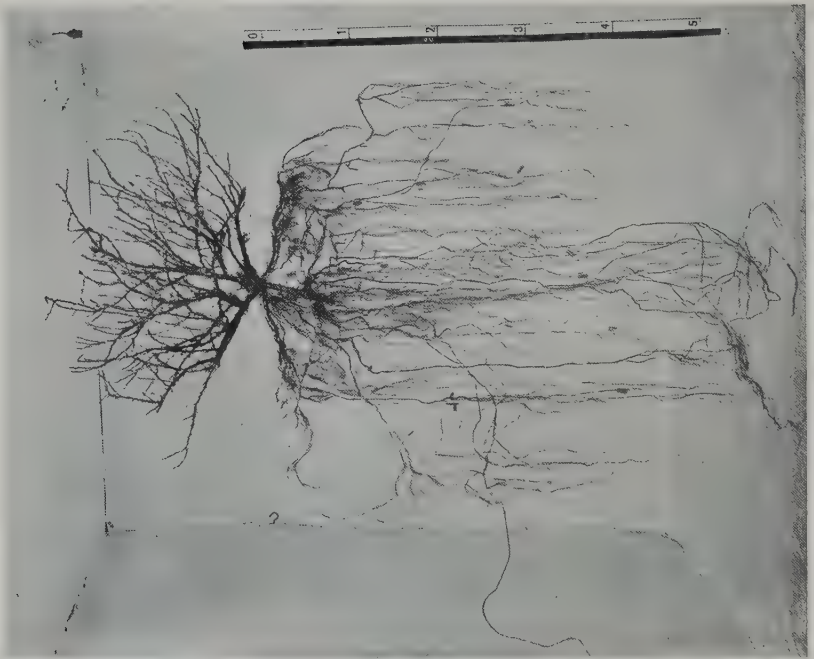
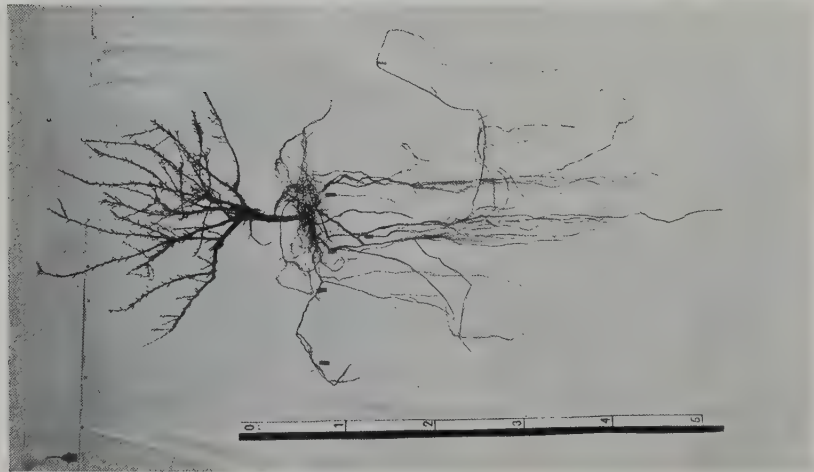
PLATE V.



Eight-year-old Dr. Jules pear on Angers Quince rootstock (Quince A).

Compare with Plate II.

The root system is reconstructed in its original relative position. The measure is marked in metres and tenths.



Eight-year-old Whitesmith Gooseberry.

(Left.) Not manured in year of planting. (Right.) Manured with fifty loads of farmyard manure in year of planting. The root system is reconstructed in its original relative position, except that the roots resting on the floor should continue downwards. The measure is marked in feet.

TABLE II.

*Effect of Manuring, Rootstock, and Variety**(a) on Depth of Rooting, and**(b) on Ratio of Stem Weight to Root Weight of Pears.*

Variety	Dr. Jules.		Conference.		Dr. Jules.
Rootstock	on Seedling Pear.		on Quince A.		on Quince A.
Treatment	not manured.	manured.	not manured.	manured.	manured.
Tree No.	P1.	P3.	P2.	P4.	P5.
Weight of roots, gm.	1,637	4,066	869	2,044	1,197
(a) <i>Depth of roots :</i>					
Percentage of weight above					
30 cm. deep	16.6	32.4	64.3	71.3	69.2
30 to 100 cm. deep	54.3	47.3	20.7	18.3	22.4
below 100 cm. deep	29.1	20.3	15.0	10.4	8.4
(b) <i>Ratio of stem weight to root weight</i>	1.95	2.33	2.17	2.57	3.64

100 cm.=3.28 ft.

1,000 gm.=2.2 lb.

Ratio of Stem Weight to Root Weight.

The ratio of stem weight to root weight shown in Table II gives some interesting comparisons. The unmanured Dr. Jules on seedling pear has 1.95 grammes of branch for every 1 gramme of root, while the manured Dr. Jules on seedling pear has 2.33 grammes of branch for every gramme of root. The Conference on Quince A also has a larger amount of branch per unit of root on the manured tree than on the unmanured tree, the figures being: manured, 2.57; and unmanured, 2.17 gm. branch per gm. root.

It thus appears that the manurial treatment has not only produced a greater amount of root, but also a greater amount of branch per unit of root. This fact, provided it is confirmed by observations on larger numbers of trees, would appear to be a natural consequence of the greater availability of the nutrients in a manured soil.

Conclusions on Manuring.

From the above figures it is clear that on this sandy soil, which is deficient in organic matter, the application of a good dressing of farmyard manure in the year of planting has given the tree a good start and enabled it to form a good root system. This root system has been able to function efficiently and support a good branch system, instead of spending most of its "energy" searching the soil for food, as appears to be the case with the unmanured root system on this poor soil.

(c) ROOTSTOCK EFFECT.

A comparison between seedling pear roots and Quince A roots both bearing the variety Dr. Jules is given by trees P3 and P5, which are illustrated in Plates II and V and described in Tables I and II.

Size and Distribution.

The photographs show clearly how the quince stock has produced very much finer roots than the seedling pear. There is a complete absence of large descending roots such as the seedling pear stocks have. The fine quince roots continued with little or no tapering for long distances, however, (Plate IV) and some of them struck vertically downward to a maximum depth of 247 cm. (8 ft. 1 in.). The quince stock has produced a smaller tree than the seedling pear (Table I, P3 and P5).

The maximum depth of the quince root was a little less than that of the pear, and 69·2 per cent of the weight of the quince root was less than 30 cm. deep compared with 32·4 per cent of the seedling pear root (Table II). Only 8·4 per cent of the weight of the quince root was below 100 cm. (3·28 ft.), but 20·3 per cent of the weight of seedling pear root was below 100 cm. These figures for size and depth are strengthened by those for the Conference pear on Quince A (trees P2 and P4), which have a rather similar depth distribution.

Stock Effect on Ratio of Stem to Root.

The Dr. Jules on Quince A has 3·64 grammes of branch per gramme of root, while the comparable Dr. Jules on seedling pear has but 2·33 grammes of branch per gramme of root (Table II). This illustrates the point that weight for weight the quince root is more efficient than the seedling pear root. The difference probably lies mainly in the type of root, for 50 metres of the fine quince root weighs much less than 50 metres of the larger seedling pear root, but it probably has just as much actual absorbing area.

There were a number of quince roots over 1 cm. diameter adjoining the trunk, but they tapered very quickly to the typical fine roots shown in the photographs. These roots, although so thin, were quite tough—a fortunate point for the excavator.

Conclusions Concerning Rootstock.

The Angers Quince type of root system is totally different from the seedling pear type of root. No actual primary tap root was found on the seedling pears, but they have many strong vertically descending roots, and a root system which can in the main be described as coarse and deep. The Angers Quince roots were much finer and more numerous, and the root system, though penetrating to almost as great a maximum depth as the seedling pear, was in the main shallow. The quince root system was in many respects similar to the root systems of

certain of the Malling types of apple stock (1), though most of the apple roots were larger than the quince roots. The habit of forming a more or less horizontal scaffolding from which roots turn to descend vertically (Plate IV) is very similar, however. On the whole it would appear that the quince root systems explored the soil rather more evenly than did the seedling pear root systems.

The vigour of the seedling roots was evidently much greater than that of the scion variety, as shown by the large bulge at the unions illustrated in Plates II and III. The bulge at the union of the quince stock and its scion is not so large, as shown in Plate IV.

(d) EFFECT OF VARIETY ON THE ROOT SYSTEM.

A comparison between two varieties of pear both growing on the same root-stock is given by trees P4 and P5, which are respectively Conference and Dr. Jules on Angers Quince stock (Tables I and II). Since there is only one tree of each, with no further data to check by, no very detailed comparison is possible. The most striking thing about the figures is their similarity. Both trees were very similar in height, depth, branch spread and root spread. No difference in the appearance, form, nor type of root was noticeable during the excavation. In each case the typical fine quince roots were found, and there was nothing to show that the scion variety had exercised any qualitative influence on the root system.

The most striking difference lies in the ratio of branch weight to root weight. The Dr. Jules had 3.64 grammes of branch per gramme of root, and the Conference only 2.57 grammes of branch per gramme of root. This therefore agrees with previous work that has found the effect of the scion variety (when worked on the stock stem) on the root to be quantitative rather than qualitative (3 and others).

IV. THE GOOSEBERRY ROOT SYSTEMS.

(a) GENERAL CHARACTERISTICS.

The general appearance of the gooseberry root systems is seen in Plate VI. There is a tendency for the roots to grow in two whorls, one arising at the basal end of the original cutting, and the other just below ground level. Some roots grew nearly horizontally, and others sent down vigorous vertical roots, which under these conditions reached the surprising maximum depth of 247 cm. (8 ft. 1 in.). Some of the roots stopped or turned on reaching the hard layer at about 100 cm., and others continued downwards. These descending roots often divided up into three or four roots, which continued downwards 5 to 10 cm. apart.

The gooseberry roots were softer and more succulent than the pear roots, although quite woody and strong. The root bark had a tendency to flake off in grey-white layers, and the outer part of the root had a distinct reddish tinge.

Some whitish translucent ends were found on the gooseberry roots, apparently in active growth, as early as February 12th. The stems were quite dormant at this time.

(b) EFFECT OF MANURE ON GOOSEBERRIES.

The very great increase in size of the manured bush over the unmanured one is evident in the photographs in Plate VI. The actual measurements of the bushes excavated are given in Table III.

TABLE III.

Effect of Manuring on Root and Stem Growth of Gooseberries.

8-year-old Whitesmith Gooseberry.						
Treatment	Not manured.			Manured.*		
Bush No.	G1.	G2.	mean.	G3.	G4.	mean.
Stem weight, gm.	816	1,909	1,362	2,180	2,130	2,155
Root weight, gm.	863	1,009	936	2,623	2,452	2,537
Total weight, stem and root	1,679	2,918	2,298	4,803	4,582	4,692
Ratio of stem weight to root weight	0.94	1.9	1.45	0.83	0.87	0.85
Maximum branch height, cm.	90	74	82	102	89	96
Maximum root depth, cm.	150 +	200	175	182	247	214
Mean branch spread cm.	112	104	108	127	117	122
Mean root spread cm.	110	160	135	160	175	167

100 cm. = approx. 3.28 ft.

1,000 gm. = 2.2 lb.

* The manurial treatment was 50 loads (approximately 100,000 lb.) of farmyard manure per acre in year of planting.

It will be seen that there is considerable variation in size between the two unmanured bushes, G1 and G2. Although smaller in height and spread than G1, G2 happened to be a thick and heavily branched bush, and was much stronger than the majority of unmanured bushes. Even allowing for this natural variation, it is clear that the manured bushes were much stronger than the unmanured ones. The mean root weight for each pair of bushes is, unmanured, 936 gm., and manured, 2,537 gm.

The appearance of the root systems in Plate VI suggests that the unmanured root never got a good start, while the manured root was able to get nourishment not only to explore the soil thoroughly but to build a good head. The masses of bushy fibrous root near the surface can also be seen in Plate VI.

Ratio of Stem to Root.

The ratio of stem to root of the gooseberries affords an interesting contrast to that of the pears. In the case of the unmanured gooseberries, it is 0.94 and 1.90, with a mean of 1.42. In the manured bushes the ratio is 0.87 and 0.83, with a mean of 0.83. That is the *unmanured* bushes have a higher amount of

top per gramme of root than the manured bushes have. This is the opposite to what occurred in the pear trees. The explanation may possibly lie in the succulent nature of the root. In the gooseberry (and also in the black currant, discussed below) the root forms a larger proportion of the total plant weight than it does in the case of the pear, and it quite possibly has a greater storage function than the slender branch system. If this is so it would seem reasonable for the root system to build up relatively more heavily than the branch system under good nutritional conditions. The data here available are really insufficient to form more than a starting point for an investigation into this very interesting problem.

Table IV shows the percentage of root weight at different depths. On account of the considerable variation between the two unmanured bushes no very definite conclusions can be drawn, but the figures suggest that on the whole the manured root systems were relatively shallower than the unmanured (as was the case with the pears).

TABLE IV.

Effect of Manuring on Depth of Rooting of Gooseberries.

8-year-old Whitesmith gooseberries.								
Treatment*				Not manured.			Manured.	
Bush No.				G1.	G2.	mean.	G3.	G4. mean.
Root weight, gm.				863	1,009	936	2,623	2,452 2,537
Percentage of root weight :								
above 30 cm.				61.2	33.4	47.3	64.0	59.5 61.7
30 to 100 cm.				37.9	47.0	42.4	25.9	25.6 25.8
below 100 cm.				0.9†	19.6	10.3	10.1	14.9 12.5

* For full details see Table III.

† A few of the deepest roots could not be obtained in this (the preliminary) excavation. This figure is therefore unduly low.

V. THE BLACK CURRANT ROOT SYSTEMS.

(a) GENERAL CHARACTERISTICS.

The root excavations of the black currants were complicated by the fact that in some cases two cuttings had been planted in one position, so forming a double bush and a double root system, which it was impossible to separate. Usually there were one or two large main roots, descending in a rather crooked downward course and a number of laterals spreading through the soil from these roots. Many of these roots, and also some shallow ones arising from the crown of the plant had a very dense growth of fine white rootlets round them, giving a "fuzzy" or bottle-brush-like appearance.

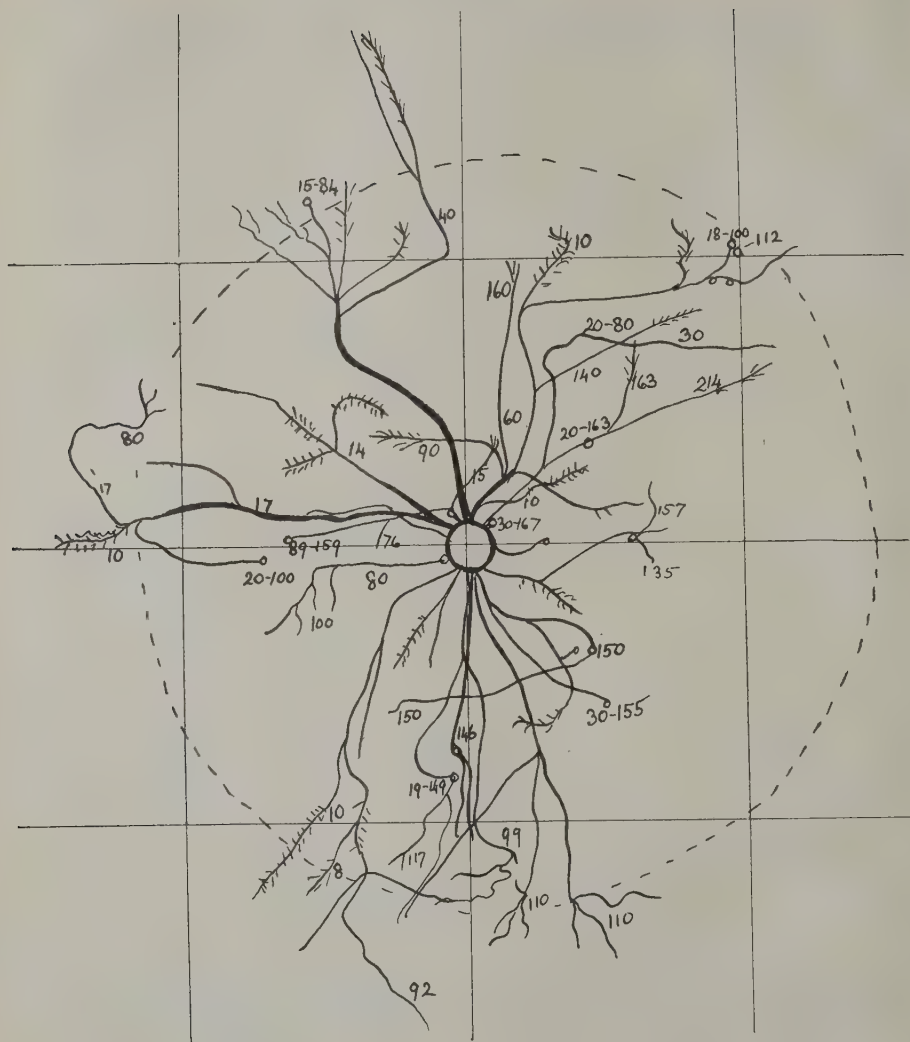


FIG. 3.

Root plan of eight-year-old Seabrook's black currant, manured.

The figures indicate depth in centimetres of adjacent root. The small circles indicate descending roots and the figures beside them the upper and lower limits of the root. The dotted line indicates branch spread. The plan is ruled in half-metre squares.

The main roots, though quite woody and very tough, were fleshy and succulent compared with the pear roots, and were whitish yellow in colour. Many laterals about 2 mm. in diameter arose from the main roots. They were also whitish yellow in colour and were often comparatively smooth. They spread through the soil in all directions. It was not possible to reconstruct any of the black currant root systems, but the root plans of manured and unmanured bushes in Figs. 3 and 4 show the crooked habit of these roots, and also show

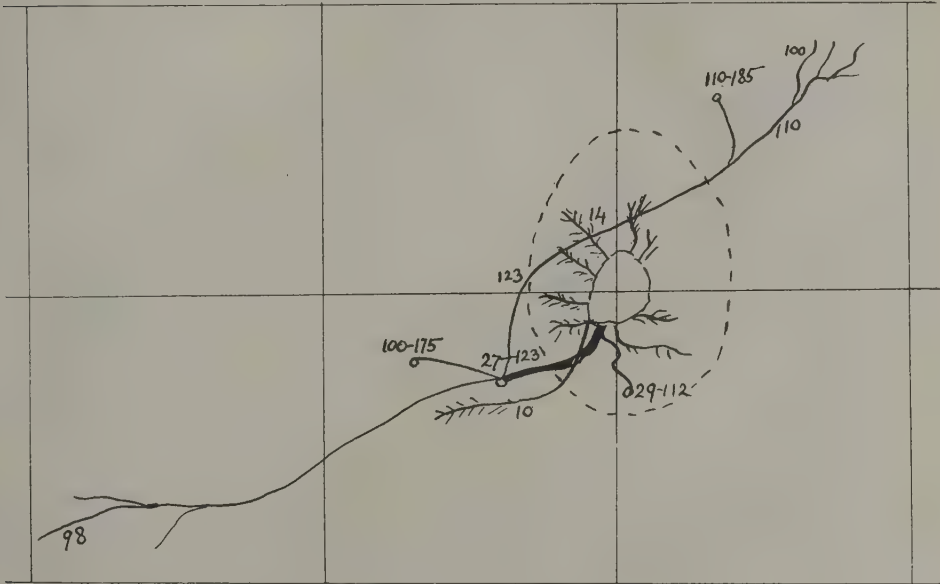


FIG. 4.

Root plan of eight-year-old Seabrook's black currant, unmanured.

The figures indicate depth in centimetres of adjacent root. The small circles indicate descending roots and the figures beside them the upper and lower limits of the root. The dotted line indicates branch spread. The plan is ruled in half-metre squares.

how in the case of the manured bushes the roots did not spread much farther than the branches.

The black currant root systems filled the soil to a depth of 100 to 150 cm. (or roughly 3 to 5 ft.) and the deepest of their roots penetrated to 214 cm. (7 ft.).

Black currant roots apparently in active growth and showing white ends with root hairs, were noted at a depth of over 100 cm. during the excavations. The branches were dormant at this time.

TABLE V.

Effect of Manuring on Root and Stem Growth of Black Currant Bushes.

8-year-old Seabrook's Black currant.							Not manured.†	Manured.*
Treatment	..	..	..	..	..	..		
Mean maximum branch height, cm.	..	..	..	..	..	..	70	115
Mean maximum root depth, cm.	..	..	..	..	..	..	172	188
Mean branch spread, cm.	..	..	..	..	..	..	45	116
Mean root spread, cm.	..	..	..	..	..	..	75	147
Branch weight, gm.	..	..	..	..	..	..	603	2,890
Root weight, gm.	..	..	..	..	..	..	386	1,973
Total weight, gm.	..	..	..	..	..	..	989	4,863

100 cm. = 3.28 ft.

1,000 gm. = 2.2 lb.

* The manurial treatment was 50 loads (approximately 100,000 lb.) farmyard manure in year of planting.

† The figures in the "not manured" column are the mean of two bushes, and those in the "manured" column are the mean of three bushes.

The figures in Table V show how manurial treatment has produced bushes which are much greater in height, spread and weight than the unmanured bushes. The mean total weight of the unmanured bushes was 989 gm. and the mean total weight of the manured bushes was 4,863 gm. The contrast visible in the field was as striking as these figures. Compare also Figs. 3 and 4.

No figures for stem root ratio are given in this case, since variation in this figure between the individual bushes was so great that the mean would be misleading, while space does not permit giving the figures in full.

In weight of root at different depths the manured bushes showed close agreement. About half their root weight was deeper than 30 cm. and about one-tenth of their root weight was deeper than 100 cm. The unmanured bushes again showed considerable variation.

GENERAL DISCUSSION OF RESULTS.

The results obtained in each part of the work have been fairly fully discussed in the various sections of this paper, and are briefly recapitulated in the summary. The outstanding point all through has been the depth of the roots, showing that these tree and bush fruits draw on an area extending much deeper than the top soil or immediate subsoil. In this case the deeper layers evidently supplied moisture, and probably downwashed plant food, which made the roots grow in the deeper soil in spite of the fact that it was harder, and certainly did not constitute the line of least resistance to the roots.

The root systems of the pears often overlapped those of the gooseberries and black currants, but showed a tendency to develop more strongly in the areas free

from other roots, showing that root competition was a factor to be reckoned with.

It must be remembered that these studies were made on one soil type only—a deep sand. Other soils would undoubtedly modify the root systems in various ways. A black currant bush of similar size excavated from a heavy clay, for instance, had a relatively more constricted root system than these bushes in sand.

ACKNOWLEDGMENTS.

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The author tenders his thanks to the Soil Survey Committee for their permission to publish this special piece of work as a separate study. He thanks also the Soil Survey workers for their collaboration and assistance; the owner of the plantation, J. T. Pierce, Esq., for permission to excavate the trees; and the authorities of the Dominion Experimental Station, Summerland, B.C., for having this report typed in their office during the writer's stay in British Columbia.

SUMMARY.

1. The complete root systems of five pear trees, four gooseberry bushes and nine black currant bushes were excavated from an eight-year-old plantation on a sandy soil at Wrotham Heath, Kent.

2. Root plans and weights were obtained, and the root systems of three pears and two gooseberries were reconstructed and photographed.

3. The comparisons available were: (1) pears, gooseberries, and black currants (a) manured with fifty loads (about 100,000 lb.) farmyard manure in year of planting, and (b) not manured; (2) pears on seedling roots and on Angers quince rootstocks; and (3) two varieties of pear on the same rootstock.

4. The seedling pear root systems consisted of a number of strong roots descending nearly vertically downwards with some roots spreading almost horizontally through the soil to a distance much wider than the branch spread (and more nearly equalling the branch height). The roots encountered a hard and gravelly layer at about 100 cm. (3·28 ft.), which checked or turned some of them. Others penetrated to a maximum depth of 337 cm. (11 ft.). At this depth they were submerged in water (in February, 1930) but appeared to be quite healthy.

5. The Angers quince root systems consisted of a fairly shallow scaffolding of main roots from which other roots descended vertically to a maximum depth

of 247 cm. (8 ft. 1 in.). Most of the roots were very thin, but tough. The bulk of the root system was shallower than in the case of the seedling pears.

6. The gooseberry roots were woody but yet fairly soft and succulent. The root spread was not much greater than the branch spread. The root depth was considerably greater than the branch height. Gooseberry roots reached a maximum depth of 247 cm. (8 ft. 1 in.).

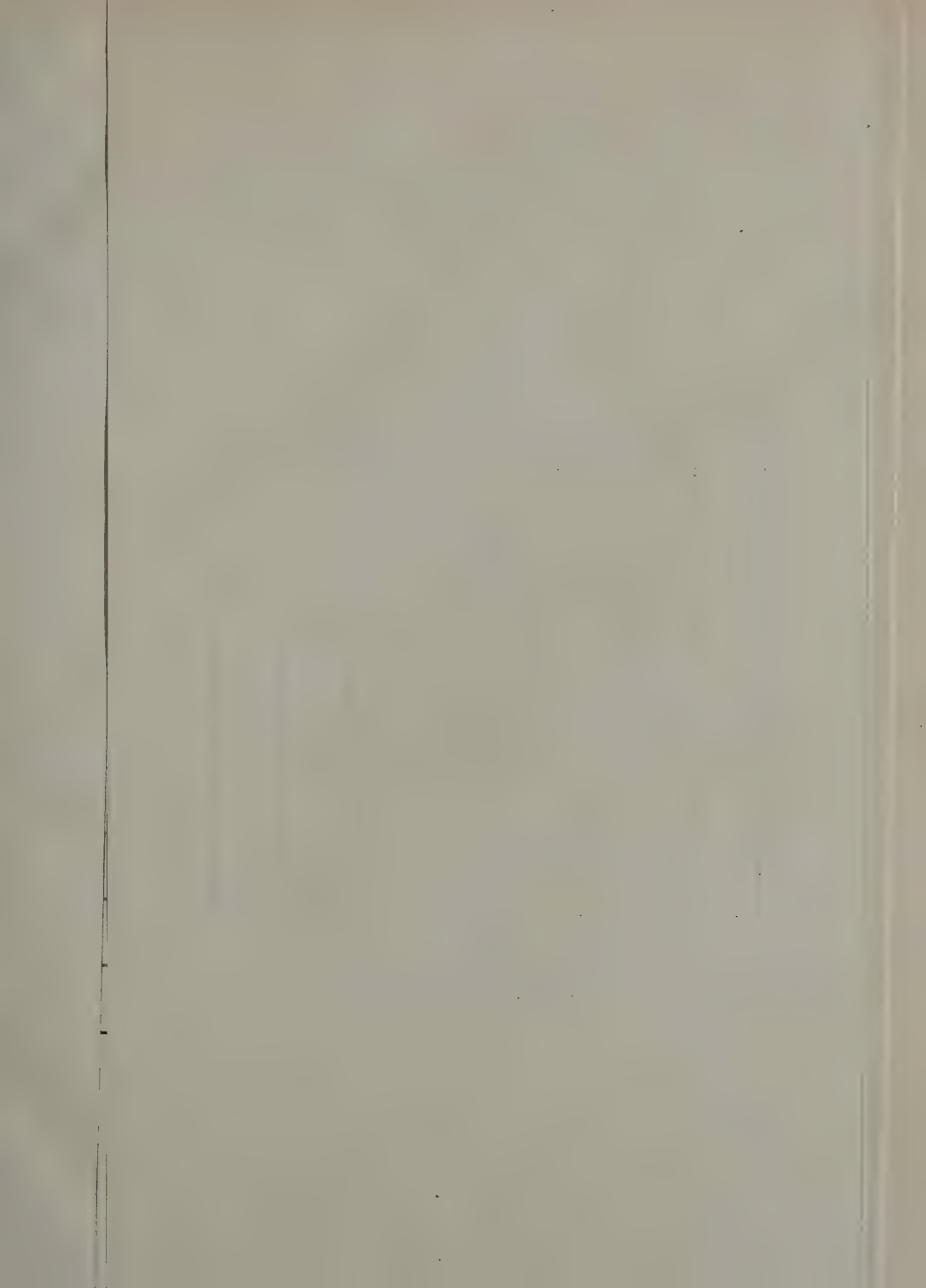
7. The black currant roots were also woody but succulent, and with a dense covering of fibrous root near the soil surface. They descended more or less in a cone beneath and extending rather beyond the branches, to a maximum depth of 214 cm. (7 ft.).

8. The manurial treatment very greatly increased both the root and top growth of the pears, gooseberries and black currants. While the total amount of root was increased, the root systems of the manured trees and bushes tended to be relatively more compact than those of the unmanured trees and bushes. The ratio of stem to root weight was increased by manuring in the case of the pears, and decreased in the case of the gooseberries.

9. Actively growing roots were found on pears, gooseberries and black currants in February, 1930, while the tops were still dormant.

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STUDIES ON *BYTURUS TOMENTOSUS* FABR.

III. FURTHER EXPERIMENTS ON ITS CONTROL ON RASPBERRIES, LOGANBERRIES AND BLACKBERRIES*

By W. STEER

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INTRODUCTION.

Objects.—The main objects of the experiments on raspberries and loganberries described in the present paper were :

1. To obtain final field scale confirmation of the excellent results obtained in past seasons by spraying twice with Derris, and at the same time to standardize the Derris used from an experimental viewpoint.

2. To follow up the promising indications obtained in 1931 with a Derris dust of known rotenone content.

3. To attempt to kill the larvae at a rather later stage in their development than was originally intended. In 1931 an application of Nicotine a few days before picking began was partially successful, and the inference was drawn that a satisfactory measure of control might be obtained with two late Nicotine sprayings or with a single late Derris spraying. Further support for this hypothesis was provided by observations which suggested that even on loganberries the larvae do not do any damage of consequence till quite late in June, and that most of the damage may, under our conditions, actually occur as a result of the larvae feeding on the drupels early in July. Moreover, although hatching begins in the middle of June, it does not reach its height till late in the month.

Sprays and Dust Used.—The Derris used in these trials was bought at 2s. a pound from the same source as that used in 1931. It differed markedly from the 1931 sample in being unusually rich in rotenone (5.87 per cent) and was very finely ground.

In view of the great dilution necessary to make up this Derris into a spray containing the very small amount of rotenone required, some doubt was felt as to the chances of getting an even distribution. It was thought advisable,

* The previous papers of this series are :

- I. "The Loganberry Beetle." *East Malling Res. Sta. Ann. Rep.*, 1931 (II Supplement, 210-221).

- II. "Further Observations on the Habits of the Raspberry Beetle, with Special Reference to the Control of the Pest by means of Derris." *Journ. Pom. and Hort. Sci.*, 1932, 10, 1-16.

therefore, to test it at two different concentrations, and whilst a standard strength of $13\frac{3}{4}$ ozs. per 100 gallons (rotenone content 0.005 per cent) was used throughout for the major issues, double this strength (rotenone content 0.01 per cent) was also used on one series of plots in the raspberry spraying trial.

Soft soap was added to the Derris spray at the rate of 5 lbs. per 100 gallons throughout the trials. Preliminary tests showed that for our water this quantity of soap ensured adequate wetting.

The proprietary Derris and Soap preparation used chiefly as an additional "Control" in the raspberry spraying trial, was the one used with success in previous seasons.

The Derris dust was composed of 1.6 per cent by weight of the finely ground Derris described above and 98.4 per cent of China Clay. The rotenone content was thus the same as that of the dust used last season (0.09 per cent approximately). Mixing was somewhat crudely effected by means of a sieve.

The Timing of the Spray.—With the double spraying method the two applications of Derris were made in accordance with the rules enumerated in a previous report (2). The first spraying was given on raspberries about ten days, and on loganberries ten to fifteen days after the beginning of flowering. The second spraying followed after an interval of about ten days. Previous experiments had shown that on raspberries there is some latitude as regards the exact time of application. In one of the trials, therefore, the effect of delaying both applications for a few days was tested to see if similar latitude existed on loganberries.

In the case of Nicotine one application was given to raspberries late in June (27th) before the larvae had begun to do serious damage, followed by another early in July (2nd). The date of the second spraying corresponded with that of the single application which gave a partial control in 1931.

With the single spraying method the one application of Derris was given fairly late in June (23rd on raspberries and 25th on loganberries). This amounted to a test of the value of the second application of the double spraying method.

Notes on Application and Methods of Recording Results.—The sprays were applied for the most part by means of a Cascade hand pump sprayer supplying one nozzle and working at about 200 lbs. pressure. Hessian screens were used where necessary to prevent spray drift. The Kings Acre Berry plants were sprayed with a knapsack.

Wetting was excellent and no deleterious effects were observed on foliage or fruit.

The weather was favourable throughout the spraying programme. The first rain after spraying (0.58 inch) fell on the night of June 30th. A further

0.1 inch fell on July 5th, making a total fall of 0.68 inch between spraying and the beginning of picking (considerably more than last year).

All infestation counts were made on random samples with the aid of a mechanical hand counting machine. This method has proved to be perfectly satisfactory in the past and provides data which are eminently suitable for statistical analysis. The data on the effect of spraying on the weight and quality of the crop were compiled from the weights of the ordinary commercial pickings.

Acknowledgments.—The writer is again greatly indebted to Dr. Tattersfield of the Rothamsted Department of Insecticides and Fungicides, whose analyses and advice determined the rates of dilution of Derris used in these trials.

Thanks are due to Mr. T. N. Hoblyn for valued assistance in planning the layout of the trials, and to him and Miss Joyce Edgar for the analyses of the results.

Thanks are also due to many members of the recording staff, too numerous to mention individually, for their help with the weighing of the raspberry crop, and to Mr. S. Arney and Miss K. Cornford for help with some of the loganberry weighings.

1932 SPRAYING AND DUSTING TRIALS.

I.—Raspberries.—Three Applications of a Derris Dust.

Layout.—This trial was carried out on twelve rows of Lloyd George raspberries comprising one-fifth acre, and was divided into four blocks each containing one dusted and one control plot.

Application.—The dust was applied early in the morning on June 13th, 20th and 27th, with a Niagara rotary hand duster. At the first and second dustings the rate of application was about the same as last year, rather less than 100 lbs. per acre. The third application was a much lighter one, owing to the fear of leaving an unsightly deposit on the fruit.

Weather conditions were moderately favourable throughout.

Observations.—The dust was found to affect the adult beetles to a much greater extent than did the Derris sprays applied in another part of the same field. On the morning of June 14th several dead and paralyzed beetles were found under dusted plants, and fewer could be beaten from dusted than from either control or sprayed rows. This does not agree with an observation made last season when, however, complications may have arisen as a result of using China Clay on a control plot. The dust is certainly very toxic to the adults.

When records were taken two random samples of 100 berries were taken from each of the eight plots, six such sets of records being made during the course of the picking season.

TABLE I.

Raspberries. *Effect of Three Applications of a Derris Dust containing 0.09 per cent rotenone.*

Mean Infestation per sample of 100 Berries.

Date of each picking.	Derris Dust (rot. 0.09%) 3 applications.	Controls. Not dusted.	Standard error.	Significant difference.
July 11th	8.2	72.4	} 2.1	6.0
July 13th	9.0	69.7		
July 15th	10.5	82.5		
July 19th	13.9	74.2		
July 21st	17.7	85.0		
July 28th	15.5	69.0		
Six Pickings	12.5	75.5	0.8	2.5

Effect of the Dust on the Infestation of the Fruit.—The dusting treatment gave a very serviceable measure of control (Table I), but was less efficient than either one or two applications of a Derris spray of much lower rotenone content (Fig. 1).

A white deposit (due to the China Clay carrier) was noticeable especially in the earlier pickings, but was on the whole less obvious than that found last season. This difference was probably due to the much lower rate of application of the third dusting.

II.—Raspberries.—Double and Single Spraying.

Layout.—This trial was carried out on two-thirds acre of Lloyd George raspberries consisting of twelve long rows. The accompanying plan shows the

12	.....	.....	.....
11	 C.	 E. ....	.....
10	.....	.....	.....
9	.....	.....	.....
8	.....	.....	.....
7	 F.	 B. ....	.....
6	.....	.....	.....
5	.....	.....	.....
4	.....	.....	.....
3	 D.	 A. ....	.....
2	.....	.....	.....
1	.....	.....	.....

Explanation of Treatments :

A=Proprietary Derris applied June 13th and 24th.

B=Derris (rotenone 0.005) applied June 13th and 23rd.

C=Derris (rotenone 0.01) applied June 13th and 23rd.

D=Unsprayed controls.

E=Nicotine and soap applied June 27th and July 2nd.

F=Derris (rotenone 0.005) applied June 23rd.

arrangement of the six treatments in one of the four randomized blocks. The dotted lines represent rows of raspberries and the continuous lines plot boundaries.

Observations.—Immediately after the first Derris spray had been applied a number of adults were found on the ground, apparently affected by the spray. On the day following spraying also a few dead and some paralyzed beetles were found.

Seven sample pickings were made during the period July 12th to 28th, for the purpose of estimating the effect of the sprays on the subsequent infestation of the fruit. At each of these pickings two random samples of 100 berries were taken from each plot (one sample from each of the two middle rows) and the numbers of infested berries recorded. The results are shown in Table II.

TABLE II.
Raspberry Spraying Trial.
Mean Infestation per sample of 100 Berries.

Date of each picking.	Proprietary Derris twice.	Derris (rot. 0.001) twice.	Derris (rot. 0.005)		Nicotine twice.	Controls unsprayed.
			twice.	once.		
July 11th	0.5	0.6	5.6	7.1	3.7	75.6
July 13th	1.5	0.6	2.0	3.9	2.4	70.4
July 15th	0.7	0.4	2.9	5.2	2.5	80.9
July 18th	1.2	0.7	4.0	4.1	4.0	75.7
July 21st	1.0	0.5	6.0	10.0	7.2	85.5
July 23rd	0.5	0.0	4.2	7.5	7.0	80.7
July 28th	1.0	0.2	8.0	7.0	9.0	87.0
Seven Pickings	0.9	0.4	4.9	6.4	5.1	78.8

		Standard Error.		Significant Difference.	
		All treatments.	Excluding Controls.	All treatments.	Excluding Controls.
Individual pickings	..	0.46	0.39	1.28	1.09
Seven pickings	.. ..	0.43	0.33	1.19	0.92

Effect of Sprays on Infestation.—Table II shows that :

1. All the spray treatments gave a very effective control.
2. A Derris spray containing 0.01 per cent rotenone and 0.5 per cent soap gave the same result as a proprietary preparation of undeclared rotenone and soap content. Each of these was significantly better than any other treatment and maintained the same level of efficiency throughout the season, whilst the other

treatments each showed a very slight falling off in efficiency towards the end of the season.

3. A Derris spray containing 0.005 per cent rotenone and 0.5 per cent soap applied twice (June 13th and 23rd) gave a slightly better result than the same spray applied once only (June 23rd), but the same result as two late applications (June 27th and July 2nd) of a spray containing 0.05 per cent of 95-98 nicotine and 1.0 per cent commercial soft soap.

Commercially speaking all the sprays gave an excellent control (over 90 per cent) throughout the season.

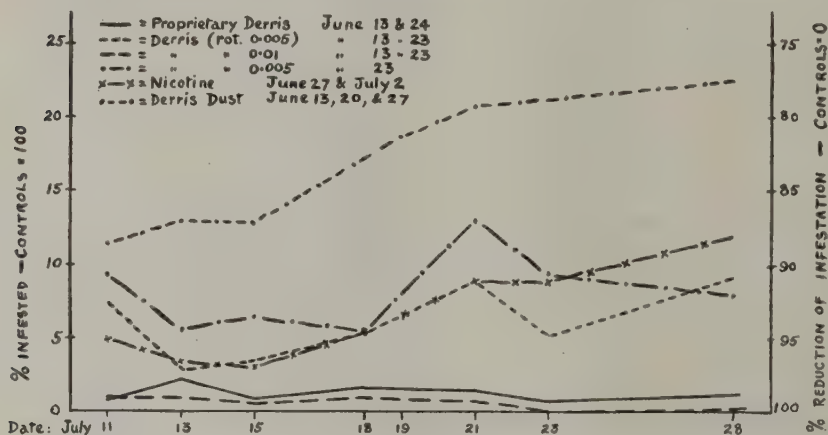


FIG. 1.

Showing relative performance of various Derris sprays, Nicotine and a Derris dust on Lloyd George raspberries.

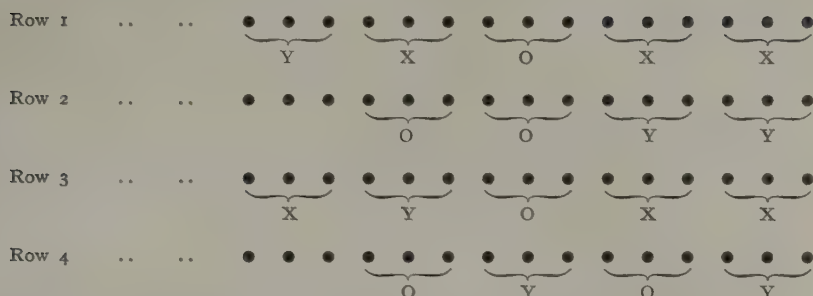
Effect of Derris on Weight and Quality of Crop.—The differences in the yield of sprayed and control plots were not so spectacular as in the loganberry trials, but were sufficiently marked to warrant the expectation of a considerable return on the cost of spraying.

Sprayed plots produced a heavier crop and a bigger proportion of Grade I (chip) fruit. The whole of the increased weight was composed of Grade I fruit.

III.—Loganberries.—Double Spraying.

Layout.—Four rows of loganberries each consisting of fifteen bushes were used for this trial. A spraying trial against Cane Spot (*Plectodiscella veneta*) was also carried out on the same bushes, but the arrangement of the plots was such that any possible interaction of the one trial upon the other could be estimated and eliminated.

The accompanying plan shows the exact layout.



Key: O=Derris (rotenone 0.005) applied June 14th and 24th.
X=Derris (rotenone 0.005) applied June 18th and 27th.
Y=Unsprayed controls.

Observations.—Six random samples of 100 berries were taken from each plot during the course of the picking season. The numbers of slightly and badly infested fruits in each sample were recorded by means of two mechanical hand counters. Berries were regarded as slightly infested when the damage was insufficient appreciably to affect their market value, e.g. when one or two basal drupels only were marked. The data afforded by these samples are shown for individual pickings in figure 2, and are summarized for the season in Table III.

The commercially picked fruit was graded by the pickers into marketable and unmarketable grades, and the weight recorded. Fig. 6 shows the weight of fruit in these grades from each of the three series of plots.

TABLE III.

Loganberries. Effect of Two Applications of a Derris Spray containing 0.005 per cent rotenone.

Mean Infestation per sample of 100 Berries.

	Sprayed.		Controls Unsprayed.	Standard Error.	Significant Difference.
	June 14th and 24th.	June 18th and 27th.			
Slightly infested ..	23.2	17.2	7.7	0.68	1.88
Badly infested ..	12.4	6.0	86.2	0.64	1.77
Total infested ..	35.6	23.2	93.9	1.04	2.89

Effect on Infestation.—It will be seen that each spray treatment gave a good commercial control, and that a few days' delay in the time of application appears to have improved the degree of control obtained. This is also borne out by the crop weight records (Fig. 6).

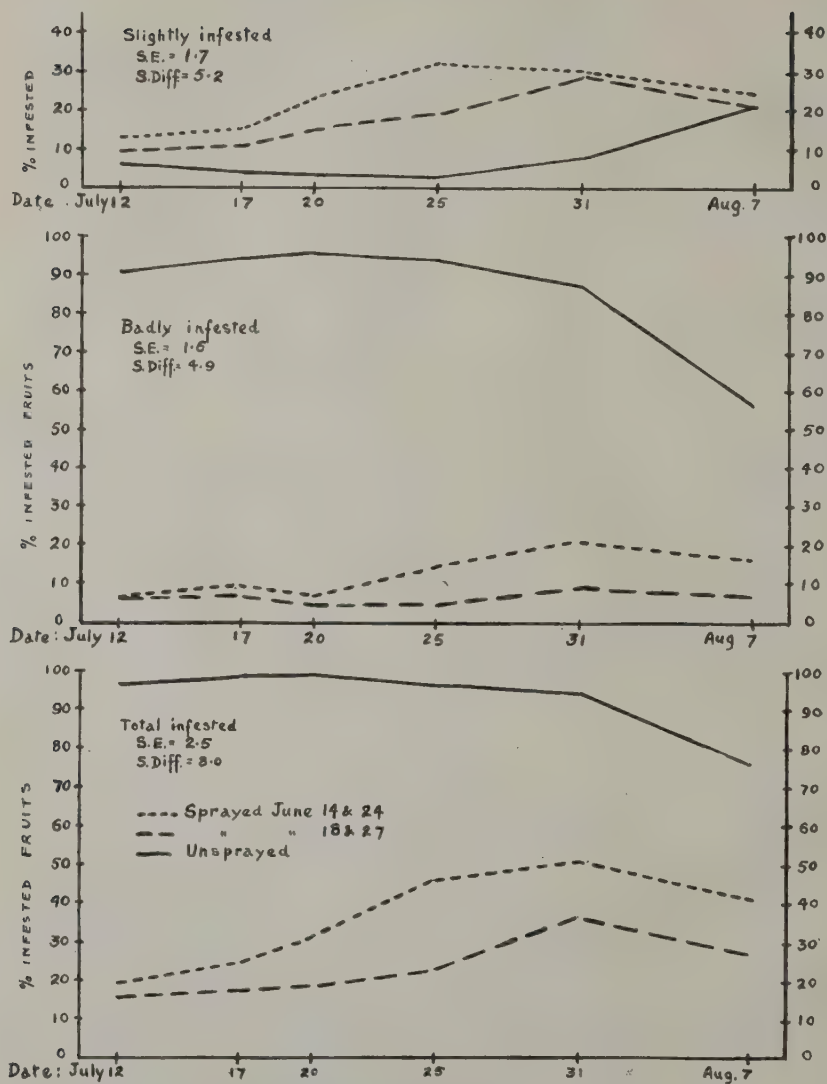


FIG. 2.

Loganberries. Effect of two applications of a Derris spray (rotenone 0.005%). Mean infestation per sample of 100 berries.

Of outstanding interest is the fact that many more slightly damaged berries were found on the sprayed than on the control plots. This may be a result of the larvae feeding for a short time before succumbing to the effects of the spray. The amount of slightly beetleed fruit from the more successful of the two sprayed treatments, although lower in actual numbers than that from the other treatment, represents a rather higher proportion of the total damaged fruit (74 per cent as against 65 per cent). Thus of the small amount of infested fruit produced by sprayed plants, the greater part is only slightly damaged, and appears to bear a definite ratio to the degree of efficiency of the spray treatment.

The normal drop in the infestation curve (Fig. 2) of the unsprayed plants did not begin so early in the season as last year and the average infestation was much higher (93.9 per cent compared with 66.3 per cent). Two factors which may be responsible are

1. beetle attack generally was rather more severe than last year ;
2. the lower yield (66 per cent of last year's crop) suggests that fewer blossoms and berries were available for egg laying.

Effect on the Weight and Quality of the Crop.—The weight records (Fig. 6) show that, just as in 1931, two applications of Derris nearly doubled the total weight of the crop and enormously increased the yield of marketable fruit.

The doubling of the total weight can readily be understood on reference to the curves of the weights per 100 berries (Fig. 3) which show that sprayed fruits weighed nearly twice as much as unsprayed. In fact, the average number of berries per pound of ripe fruit over the whole season worked out at : sprayed 121, and controls, 206.

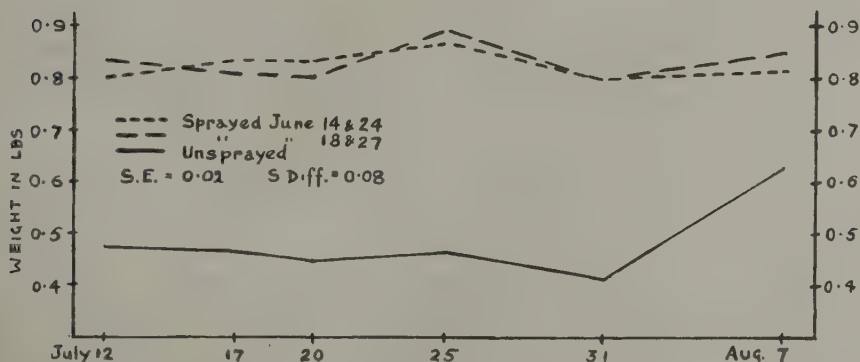


FIG. 3.

Two applications. Weight per sample of 100 berries at each picking.

Season's average : Sprayed June 14th and 24th, 0.82 ; sprayed June 18th and 27th, 0.83 ; unsprayed, 0.48 lb. per 100 berries. (S.E.=0.01 ; S.Diff.=0.03.)

In comparing the two sprayed treatments it will be observed that the one yielded 14 lbs. more fruit than the other, but, since it is evident from Fig. 3 that no significant difference existed between the weight of 100 berries of either series, this difference can scarcely be significant. The proportion of marketable fruit, however, bears a close relation to the beetle infestation and bears out the conclusion that a delay in the time of spraying somewhat improved the degree of control obtained.

IV.—Loganberries.—Single Spraying.

Layout.—This trial was planned on modern statistical lines as an intensive experiment to test the effects and possible interrelation of :

1. Spraying for beetle.
2. Spraying for Cane Spot, and
3. The use of various methods of training.

The beetle control experiment was affected by the other experiments only insofar as the layout and the technique of recording were concerned, and is therefore the only issue dealt with here. There were four sprayed and four unsprayed plots each consisting of twelve bushes.

The one application of Derris was given on June 25th, by which time little or no damage had been done by the larvae, although a great many, possibly most, of the eggs had hatched.

Observations.—Five sets of records of the infestation were made during the picking season. At each sampling four random samples of twenty-five berries were taken from each of the eight plots, one from each of the four training treatments. The total numbers infested were counted, no attempt being made to separate the slightly and badly beetled berries. The results of these counts are shown for individual pickings in Fig. 4 and are summarized for the season in Table IV.

The commercial pickings were graded and weighed in the same manner as in the previous loganberry trial.

TABLE IV.

Loganberries. Effect of One Application of a Derris Spray containing 0.005 per cent rotenone.

Mean Infestation per sample of 100 Berries.

	Sprayed June 25th.	Unsprayed.	Standard Error.	Significant Difference.
Total infested per 100 ..	23.9	91.4	0.99	2.9

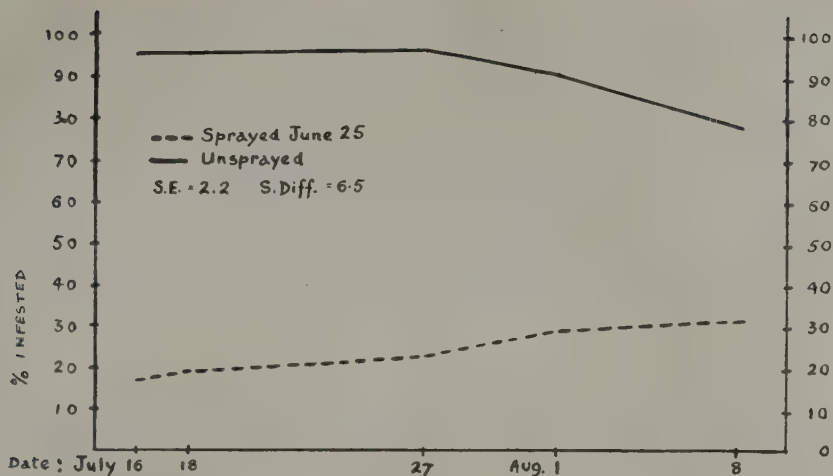


FIG. 4.

Loganberries Effect of one application of a Derris spray (rotenone 0.005%) Mean infestation per sample of 100 berries.

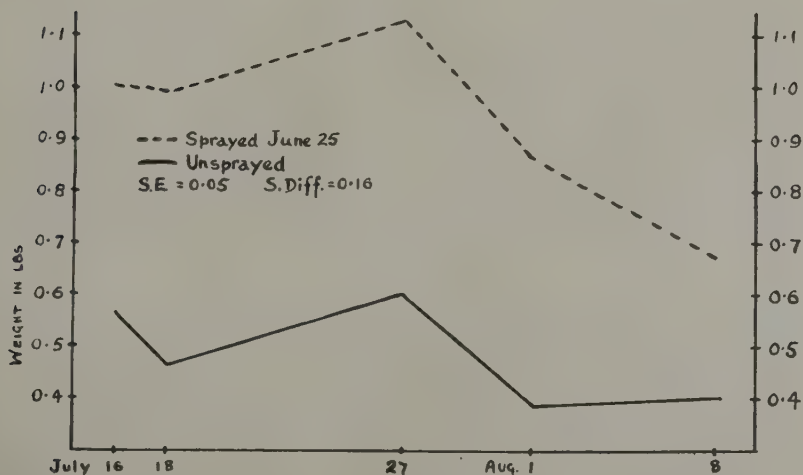


FIG. 5.

One application. Weight per sample of 100 berries at each picking.

Season's average: Sprayed June 25th, 0.94; unsprayed, 0.48 lb. per 100 berries.
(S.E. = 0.02; S.Diff. = 0.06.)

Effect on Infestation.—It is evident that one application of Derris (on June 25th) gave a satisfactory measure of control, of about the same order as that given in another trial by two applications of the same spray. As with the double spraying method, there is a tendency for the infestation to decrease on the controls and to increase on the sprayed plots towards the end of the season.

Effect on the Weight and Quality of the Crop.—Here again the total weight of fruit of all grades was doubled and the amount of marketable fruit enormously increased (Fig. 7). Similar differences in the weights of equal numbers of sprayed and unsprayed berries are also apparent (Fig. 5). The average number of berries per pound of ripe fruit averaged 207 and 106 on control and sprayed plots respectively.

V.—Blackberries.—Double Spraying.

Layout.—The objects of the experiments on various blackberry varieties were

1. to find a "critical period" for attacking the pest and
2. to determine as far as was possible with the limited material available whether Derris could successfully be used at such a period.

The tests were made on three varieties: Kings Acre, Himalaya and Cutleaf Berries. The "Cutleaf" was a variety purchased as such but not identical with the true *laciniatus*. There were available only three adjacent bushes of each; accordingly two bushes were sprayed and one left as a control.

The dates of spraying were calculated in the first place from theoretical considerations based on flowering records, but were subsequently modified in accordance with observations made on the hatching and movements of the larvae.

Kings Acre Berry.—As anticipated, the spraying method which had been evolved for loganberries proved to be applicable also to this very early blackberry variety. The difference between the sprayed and unsprayed bushes was very

TABLE V.

Effect of Two Applications of Derris (rotenone 0.005 per cent) on blackberries.

	Per cent infested berries.		Average weight per 100 berries.	
	Sprayed.	Unsprayed.	Sprayed.	Unsprayed.
<i>Kings Acre Berry:</i>				
Sprayed June 17th and 24th ..	6.6	99.0	0.82 lbs.	0.47 lbs.
<i>Himalaya Berry:</i>				
Sprayed July 6th and 18th ..	0.5	50.7	0.53 lbs.	0.40 lbs.
<i>"Cutleaf" Berry:</i>				
Sprayed July 9th and 19th ..	0.6	34.3	0.57 lbs.	0.46 lbs.

marked. Judging from random samples of fruit, control was practically complete (Table V), and it was obvious that spraying affected the weight and quality of the crop in much the same way as has been observed on loganberries.

Himalaya Berry.—The first spray application was calculated for the end of June, but was delayed till July 6th, about which time the larvae began to feed on the berries. Table V shows that the two sprayings gave a very good control and had a marked effect on weight and quality.

"Cutleaf" Berry.—This variety appears to be amenable to the same spraying treatment as Himalaya, and similar results were obtained with it.

CONCLUSIONS.

Number of Derris Sprayings Necessary.—The adequacy of the East Malling double spraying method (which entails spraying raspberries and loganberries in the middle and towards the end of June) must now be considered as amply confirmed. Nevertheless the 1932 trials strongly suggest that the first (mid-June) application may be superfluous, and there appears to be every reason for believing that excellent control can be obtained on raspberries and loganberries with one application of Derris late in June. This agrees with observed facts of the life history and would still further reduce the already low cost of spraying.

It is noticeable that on loganberries either method shows a slight decrease in efficiency during the latter part of the picking season. This raises an interesting question. Could not the already good measure of control obtained be still further improved by a spray applied shortly before picking begins, say, under our conditions, July 5th to 10th? If so, and if the mid-June application definitely proves to be superfluous, then the double spraying method would be modified to involve one application in the last week of June followed by a second after, say, a fortnight's interval.

Strength of Spray Fluid.—As far as our present knowledge goes it would seem that a spray containing sufficient finely ground Derris root to give a rotenone content of the order of 0.005 per cent is adequate for the control of the larval stage of this pest. The precise degree of fineness of grinding necessary remains to be investigated, but apart from any possible correlation of fineness with toxicity, it is certain that a finely ground sample is preferable to a coarse one from the practical aspect. Derris powders containing long fibres and coarse particles are difficult to keep in suspension and are apt to choke valves and nozzles, with consequent waste of time.

At present an estimation of the rotenone content appears to be the most satisfactory method of assessing the value of a sample of Derris, and such

estimations have been used as a means of standardization in the trials described herein. The rotenone and the ether extract contents of Derris root vary enormously according to species and locality, as Georgi and Teik have recently shown (1). It is obviously impossible therefore to conduct trials with sprays or dusts mixed on the basis of so much per cent of "Derris." It is also unwise at present for growers to attempt to reproduce the sprays used in these trials except with Derris of guaranteed rotenone content.

Derris Dusts.—A dust containing China Clay as carrier and sufficient finely ground Derris to give a rotenone content of the order of 0.09 has been shown to have a marked effect on the pest. As used in the East Malling trials it was less efficient than wet sprays containing 0.005 per cent rotenone, but gave, nevertheless, quite a good control. Late applications of such a dust are apt to leave an unsightly deposit on the fruit. It is possible, however, that a late application may not be necessary and that two dustings at a week's interval in the middle of June may prove adequate, since the dust is toxic to the adults as well as to the larvae.

It remains to be seen whether a dust of higher rotenone content will give markedly superior results, or whether a slight decrease in the rotenone content will be accompanied by any appreciable loss of efficiency. The latter remark applies also to wet sprays.

It is reasonably certain that fineness of grinding is quite as important in a dust as in a wet spray, if not more so.

The chief advantage of dusting is the rapidity with which it can be carried out. The argument of cheapness is scarcely tenable in view of the present high prices of commercial Derris dusts and the very low cost of wet spraying.

The Use of Nicotine.—Nicotine and soap applied twice as a direct contact spray for the larvae appears to give an excellent control on raspberries. That the second (early July) application is not of itself sufficient was demonstrated in 1931, but it still remains to be seen whether the first application alone (late June) will give satisfactory results.

In the absence of definite trials it is impossible to say whether a loganberry attack will prove amenable to Nicotine treatment.

Blackberries.—Whilst a good deal of investigation remains to be carried out on the control of the pest on cultivated blackberries, it is evident from the preliminary experiments already conducted, and from the reports of growers who have followed a spraying schedule suggested by us, that a good control is likely to be obtained by spraying such varieties as Himalaya and Cutleaf with Derris during the first and third weeks of July.

Average Efficiency of Derris Sprays and Dust.—Table VI shows the performance of various Derris sprays and the experimental dust for the last three seasons. The figures are calculated by reckoning the difference in average infestation between sprayed and control plots as a percentage of the potential (or "control") infestation. They therefore represent the percentage reduction of infestation, and unsprayed plots have the value 0.

The figures in lighter type are based on small scale experiments only.

TABLE VI.
Efficiency of Derris Sprays and Dust at East Malling.

	Wet Spray.				Derris Dust.	
	2 applications.			1 application.	3 applications.	
	1930.	1931.	1932.	1932.	1931.	1932.
Raspberries ..	—	92·6	96·4	92·0	81·1	83·5
Loganberries ..	94·0	78·0	68·5	74·0	—	—
Kings Acre Berry ..	—	—	93·3	—	—	—
Himalaya Berry ..	—	—	99·0	—	—	—
Cutleaf Berry ..	—	—	98·3	—	—	—

It seems that a more complete control can be obtained on raspberries than on loganberries by either the single spraying method or by the double spraying method *in its present form*. The habit of some of the larvae of feeding on the tips of young canes, first noted in 1931 and found to be of common occurrence in 1932, is much more marked on raspberries than on loganberries and it may well be that such larvae are more accessible or vulnerable to a late June spray than those which do not leave the fruit.

The present tendency in the East Malling loganberry spraying trials is to spray much later than was originally thought desirable and reference is made in an earlier paragraph (p. 31) to a proposal whereby it is hoped that the degree of control may be still further improved.

COST OF SPRAYING.

Raspberries.—A previous report (2) contained data on the cost of spraying a four acre plantation of Lloyd George raspberries adjoining the experimental plots, and it was shown that, using a somewhat expensive form of Derris, the cost per acre of each spraying worked out at about £3 17s.

This year a cheaper form of Derris (a proprietary powder) was used commercially on the same plantation (at 2 lbs. per 100 gallons plus 5 lbs. soft soap) and the cost of spraying very much reduced.

A 2½ h.p. machine supplying five nozzles at a pressure of about 150 lbs. was used. A recent purchase of additional piping enabled the whole plantation to be sprayed without moving the engine and thus dispensed with the need for carting water. One man was permanently employed in running the engine and mixing the spray. One nozzle less was used than last year. Spraying was carried out on June 17th-18th and June 27th-28th.

The following figures show the total cost of the two sprayings, excluding depreciation of machinery but including the time occupied in laying down and taking up the mains (about twenty-four man hours).

					£	s.	d.
Labour.							
Six men, 30½ hours each, @ 9d. hour	..	..	..	..	6	17	3
Spray Materials.							
Derris, 80 lbs. @ 2s. 2d. per lb.	..	..	..	..	8	13	4
Soap, 200 lbs. @ 3d.	..	..	..	..	2	10	0
Water, 4,000 gallons	..	..	..	..		15	0
Petrol.							
Six gallons @ 1s. 4d.	..	..	..	..		8	0
Total cost 4 acres	..	..	..	..	£19	3	7

Thus the cost per acre was £2 7s. 11d. per application.

Since the rows were unusually long, and therefore inconvenient for spraying, this may well be regarded as an outside figure. Many growers report a much lower cost, especially where a two-lance power machine could be drawn by horse along the rows.

Blackberries.—The following details were kindly supplied by a blackberry grower.

On 16 acres of Himalaya Berry, using a well-known commercial Derris at 2 lbs. per 100 gallons and a rather expensive form of soap (liquid soap at 2½ gallons per 100), the total costs of two sprayings were approximately :

Material	..	..	..	..	..	..	£20
Labour	..	..	..	..	..	..	£10
Tackle, etc.	..	..	..	..	..	..	£2
Total for 16 acres	..	..	..	..	..	..	£32

The cost of each application was thus about £1 per acre. 3,200 gallons of spray were used (about ½-gallon per plant).

Spraying was carried out between July 4th and 9th (followed by dry weather) and between July 20th and 24th (followed by rain), and the spray is stated to have been " perfectly effective except for the very early and late fruit."

General.—On the whole indications are that, with suitable apparatus, Derris spraying on raspberries, blackberries and loganberries should not cost more than £1 to £2 per acre per application.

RECOMMENDATIONS.

The results of the experiments carried out so far indicate a choice of four methods of attacking the pest in the larval stage. These are

- (i) double spraying with Derris,
- (ii) single " " "
- (iii) dusting with Derris,
- (iv) double spraying with Nicotine (on raspberries).

(i) Double Spraying with Derris.

First Application.

Loganberries, ten to fifteen days after flowering begins.

Raspberries, about ten days after flowering begins.

Second Application.

Ten to fifteen days later.

Under most conditions these times can be reckoned as the middle and end of June, say June 10th to 15th and June 20th to 30th. Phenomenal Berry, Jam berry and Laxtonberry may be included with loganberries for the purpose of spraying. The later the second application can safely be left, the better is the result likely to be.

With regard to blackberries present indications are that Himalaya and Cut-leaf should be sprayed during the first and third weeks in July, taking care to drench the fruit, flowers, flower buds and flower stalks. Very early varieties such as Kings Acre Berry should be sprayed at the same time as the Loganberry.

(ii) Single Spraying with Derris.

This amounts simply to omitting the mid-June application (on raspberries and loganberries). A thorough drenching spray should be given in the last week in June.

(iii) Derris Dusting.

Some growers may prefer to use a Derris dust rather than a wet spray in spite of the undoubted superiority of the latter when used against the larvae. Such a

dust should be applied to loganberries and raspberries about the middle of June and (as far as is known at present) to blackberries early in July. Heavy late applications should be avoided as being liable to leave unsightly deposits on the fruit.

(iv) **Nicotine.**

Nicotine 8 ozs., soap 8 lbs., water 100 gallons, has given good results on raspberries if applied late in June and again early in July, and may be so used if desired, but is more expensive than Derris and soap.

There are on the market several preparations declared to be or to contain Derris. Several of these have been tried against the pest and found to be effective at about the dilutions recommended by the makers for caterpillar and other chewing insects. It is advisable always to use fresh materials and to avoid buying Derris preparations which have been in stock for any length of time.

SUMMARY.

1. The 1932 trials confirm still further the adequacy of the East Malling double spraying method (which involves spraying raspberries and loganberries in the middle and towards the end of June).

2. They also suggest that the pest may with advantage be attacked at a rather later stage than was originally intended. Thus satisfactory results were obtained with one late application of Derris (on raspberries and loganberries) and with two late applications of Nicotine (on raspberries) applied with the object of killing the larvae just before they begin to do serious damage.

3. A spray containing sufficient finely ground Derris to give a rotenone content of 0.005 per cent, and 5 lbs. of soft soap per 100 gallons, gave excellent results on both raspberries and loganberries, whether used according to the double spraying or the new single spraying method. Besides reducing the percentage of fruits infested it had an enormous beneficial effect on the yield and quality of the crop.

4. A Derris dust containing 0.09 per cent rotenone again gave a serviceable measure of control on raspberries but was somewhat inferior to any of the wet sprays used.

5. Preliminary trials showed that the pest can be controlled on cultivated varieties of blackberries by means of Derris.

6. The cost of spraying is discussed and recommendations made as to the most suitable times for spraying.

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- (1) *Georgi, C. D. V.* and *Gunn Lay Teik*. The Rotenone Content of Malayan Tuba Root. *Malayan Agric. Journ.*, 1932, **20**, 498-507.
- (2) *Steer, W.* Further Observations on the Habits of the Raspberry Beetle, with special reference to the control of the pest by means of Derris. *Journ. Pom. & Hort. Sci.*, 1932, **10**, 1-16.

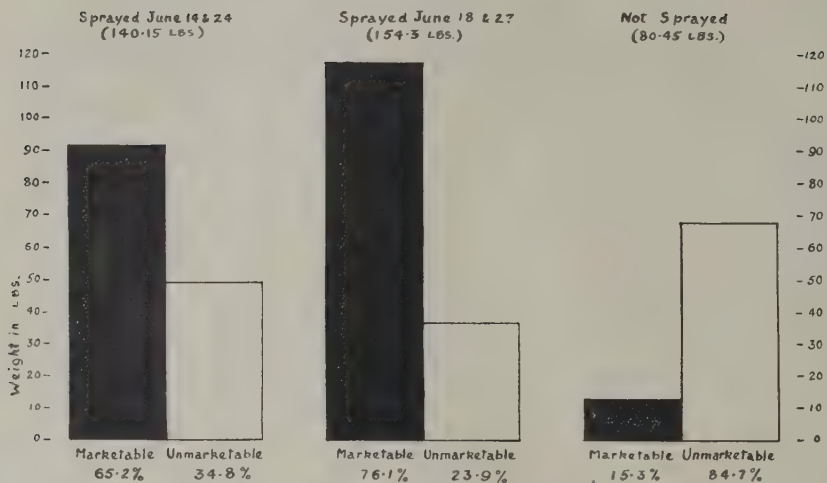


FIG. 6.

Effect of *two* applications of a Derris spray (rotenone 0.005%) on weight and quality of loganberries.

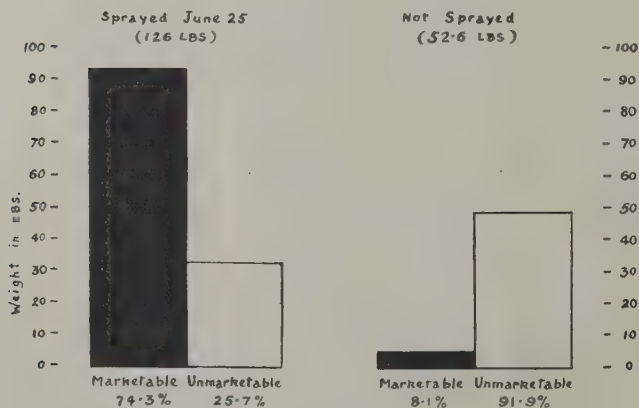


FIG. 7.

Effect of *one* application of a Derris spray (rotenone 0.005%) on weight and quality of loganberries.

THE CONTROL OF THE LOGANBERRY AND RASPBERRY BEETLE (*BYTURUS TOMENTOSUS*)

EXPERIMENTS WITH PYRETHRUM AND DERRIS WASHES AND DUSTS

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DURING the past few years a number of trials on the control of the Loganberry and Raspberry Beetle have been carried out. Two different stages of the beetle's life history have been considered the most vulnerable. Walton (4, 5) found that three successive applications of a pyrethrum emulsion when approximately one-third, two-thirds and all the flowers were fully open provided a commercial control of the pest. The spray applications were aimed at killing the maximum number of the beetles, and therefore it was recommended that the wash should be applied during the later part of sunny days when the greatest number of beetles collected in the blossoms. It is evident that the third and probably the second spraying killed also a number of larvae which had hatched from eggs laid about the time of the first application of the wash.

Steer (7) in 1931, following Walton's recommendations, was unable to obtain a satisfactory control using a proprietary wash made up according to Tutin's formula (8, 9). In the previous season he (6) had obtained a control satisfactory up to a point with the same type of wash, but did not find any decrease in the control by omitting the first application of the spray. He also carried out a series of trials with a derris wash and the results obtained in 1930 and 1931 were highly satisfactory.

In view of the probability that the pyrethrum wash used by Steer was not of the same toxicity as that used by Walton, it was decided to carry out a further trial using pyrethrum and derris preparations under comparable conditions. The principal object of the 1932 trials was to compare the results obtained with a derris wash and those obtained with a pyrethrum emulsion of known content of toxic principles. In addition they provided an opportunity of comparing the results with those from other derris and pyrethrum preparations of different concentrations and constitutions.

PARTICULARS OF THE WASHES AND DUSTS USED IN THE 1932
TRIALS.

I. WASHES.

Pyrethrum Emulsion A.—This consisted of a white oil in which a petroleum pyrethrum extract was dissolved. The oil was emulsified in such a way that it readily mixed with water to form an emulsion. It was prepared just before the date of the first spraying, which reduced the possibility of the breakdown of the pyrethrins. (It has been found that the loss of toxicity on keeping takes place very slowly, provided the concentrate is kept in an airtight container and not exposed to the light.) The wash was used at concentrations that represented by weight 1.0 and 0.25 per cent of best quality dried pyrethrum flowers. The concentration of the oil in the emulsion when used at the higher concentration of the flowers was approximately 1.5 per cent. Both concentrations of the wash killed both beetles and larvae under controlled conditions.

Pyrethrum B.—A proprietary wash made up according to the Long Ashton formula (9) and used at the rate of $1\frac{1}{4}$ gallons per 100 gallons of water gave a concentration representing approximately 0.5 per cent of the flowers. The wash at this concentration killed beetles and larvae.

Pyrethrum C.—A freshly prepared "one solution proprietary wash" containing a high concentration of the active principles of good quality flowers. When used at the rate of $1\frac{1}{2}$ pints of the concentrate to 100 gallons of water it provided a wash representing 0.25 per cent of the flowers. It was used at two strengths, 1.0 and 0.25 per cent and each killed the beetles and larvae.

Pyrethrum Extract in Kerosene.—Several grades of kerosene were tested for damage to raspberry foliage, and one containing approximately 9 per cent of aromatic constituents and a negligible quantity of unsaturated hydrocarbons was selected as the least likely to cause any appreciable damage to the foliage, flowers and berries. Petroleum pyrethrum extract was added to the kerosene in two different quantities, i.e. 3.6 cc. and 10.0 cc. per 1,000 cc. of kerosene; 3.6 cc. of extract corresponded to 100 gms. of flowers (1 lb. flowers per gallon kerosene). The atomized spray killed the beetles and the larvae.

Derris Wash.—This wash consisted of a proprietary ground derris root suspended in a soap solution, the rotenone content of the derris root estimated by Roark's method being 1.72 per cent. It was used at two concentrations, $2\frac{1}{2}$ and 5 lbs. of derris per 100 gallons of water to which 10 lbs. of spraying soap had been added; these concentrations represented 0.0086 per cent and 0.0043 per cent rotenone respectively. Both washes killed the larvae and beetles, the latter dying somewhat slowly.

Derris Emulsion.—A proprietary wash containing the toxic principles of derris root in rape oil. It was used at a concentration of $1\frac{1}{4}$ gallons per 100 gallons of water. It killed beetles and larvae.

II. DUSTS.

Pyrethrum Dusts.—In previous experiments a pyrethrum dust did not give any satisfactory control of *Byturus* (5) or of the Willow Beetle (1). However, in view of the ease of application a grower at one of the trial centres was anxious to experiment with a dust. The type (No. 1) used there was similar to that used in the earlier experiments and consisted of kaolin as a carrier, ten parts by weight containing the active principles of one part of pyrethrum flowers. A second dust (No. 2) was also tried and contained 10 per cent by weight of best quality ground pyrethrum flowers. Provided the dusts had not been exposed to the air and light for more than twenty-four hours both killed the beetles and larvae.

Derris Dust.—A proprietary derris dust was used by the grower at one trial centre and it contained approximately 10 per cent of derris and 0.18 per cent of rotenone. The dust killed the beetles and larvae and remained toxic on the foliage for at least four days, provided it was kept dry.

The pyrethrum and derris preparations are non-poisonous to man and did not cause any damage to the flowers or berries. The washes, particularly if applied during the full heat of the sun, may cause some slight and unimportant foliage damage. Of the *Rubi* attacked by the beetle, blackberries are most subject to wet spray injury whilst raspberries are rarely harmed.

METHODS OF APPLICATION.

Washes.—The spray fluids at the Long Ashton centre were applied to raspberries rapidly and efficiently with spray guns by means of a tractor drawn power outfit. The berries, flowers and foliage were thoroughly wetted, the wash being used at the rate of 500 gallons per acre.

At the Stourton centre, Worcester, the washes were applied to the loganberries by means of a horse drawn barrel pump; this method of application was slow, but the work was carried out carefully and approximately 350-400 gallons per acre were used.

Dusts.—At Long Ashton the dusts were applied by means of a hand rotary blower and at Stourton by means of a horse drawn hand rotary blower. The applications were made with approximately 80 lbs. of dust per acre.

Atomization.—In addition to the above normal methods of application, several rows of raspberries were sprayed with an atomized emulsion of Pyrethrum A. The pyrethrum kerosene was also applied in this way. The atomization was carried out by means of a special paint gun fed by compressed

air from a power driven plant. The degree of atomization of the kerosene was excellent and the bushes were enveloped with clouds of the vaporized kerosene, each berry being covered by particles of fluid. The emulsion, on account of its physical properties, did not atomize so well. The kerosene was applied at the rate of 8-10 gallons per acre, and the emulsion at 40 gallons per acre.

1932. FIELD TRIALS.

TRIAL CENTRE I. LONG ASHTON RASPBERRY PLANTATIONS.

Weather During the Application.

The weather during, between and after the applications of the washes was fine.

The trials were carried out on Baumforth "A" raspberries. Eighty-two rows, each approximately 20 yards in length, were selected as suitable on account of the uniform intensity of infestation by the beetles. Control (unsprayed) rows were arranged at intervals and buffer rows left between different treatments where there was any chance of spray or dust drift. The treatments were arranged as follows :

Rows	1—2	Control.
	3	Buffer.
	4—5	Kerosene pyrethrum 3.6 cc. }
	6—7	Kerosene pyrethrum 10.0 cc. } Atomized.
	8	Buffer.
	9—12	Pyrethrum Emulsion "A" at 1.0 per cent. Atomized.
	13—14	Buffer.
	15—17	Pyrethrum Dust II 10 per cent ground flowers.
	18—18A	Buffer.
	19—21	Control.
	22—27	Pyrethrum Emulsion "A" 1.0 per cent.
	28—30	Control.
	31—36	Derris 5 lbs. per 100 gallons water.
	37—42	Derris 2½ lbs. per 100 gallons water.
	43—48	Pyrethrum Emulsion "A" 0.25 per cent.
	49—54	Derris Emulsion.
	55—60	Control.
	61—66	Pyrethrum Emulsion "C" 0.25 per cent.
	67—72	Pyrethrum Emulsion "C" 1.0 per cent.
	73—77	Control.
	78	Buffer.
	79—82	Derris Dust.

The Time of Application of the Washes and Dusts.

The beetles were present in large numbers on the unopened flower buds. By June 12th about one-third of the flowers were open and in view of the prolonged period of opening of this first third of the blossom and the extensive egg laying that had taken place, the first application of the washes and dusts was made on June 20th. At this date numbers of larvae and unhatched eggs were present. The remaining two-thirds of the flower buds opened very rapidly and the full blossom date was June 16th. The second application of the washes and dusts was made on June 24th. During two days before June 21st there was a sudden and almost complete permanent disappearance of the beetles; therefore it was evident that the insecticides applied were directed against the larvae and not the adult beetles.

The second application of the atomized fluids and the normally applied pyrethrum emulsion on rows 22-27 were made on June 27th.

Results.

Picking commenced on July 12th, but the first pick was very small and consisted almost entirely of berries deformed by adult damage (3). The next two picks were also light for the same reason. At each pick random samples of 4 lbs. of berries with the plug were collected from each differently treated plot. From each sample 500 berries were taken at random and examined for larval damage. Examinations of those treatments that showed a very poor control after the first three counts were not continued. After the fourth pick the count was reduced to 250 berries. The total number of berries examined was 45,000 and the results are recorded in Table I on p. 44.

The derris wash (soap suspension) and dust gave a very good control of the larvae. No advantage was gained in increasing the amount of derris from $2\frac{1}{2}$ (0.043 lb. rotenone) to 5 lbs. per 100 gallons of wash. The derris emulsion gave very poor results. It is interesting to note that this wash provided a good control of Apple Sawfly (*Hoplocampa testudinea* Klug.) whereas the derris in soap suspension gave a poor control (2).

The results obtained with the pyrethrum emulsions containing the toxic principles of 1 per cent of the flowers were much inferior to those obtained with the derris, and they agreed with those obtained by Steer in 1930, both in regard to the extent of the reduction in infestation and in that the first few pickings were the least infested. The pyrethrum washes containing 0.25 per cent of the flowers and the dust did not provide a commercial control. The atomized kerosene pyrethrum and the 1.0 per cent pyrethrum emulsion did not give such good results over the same period of picking as the normally applied 1.0 per cent emulsions. It is interesting and important to note that the pyrethrum preparations containing the higher percentage of active principles gave better results.

TABLE I.
Trial I. Raspberries. Long Ashton. Percentage Infestation.

Date of Picking	..	..	..	14.7.32	18.7.32	20.7.32	22.7.32	25.7.32	27.7.32	29.7.32	3.8.32	Average Percentage Infestation.
Row No.	Treatment.											
1—2	Control ..	..	..	60.2%	39.2%	34.4%	50.4%					46.0%
4—5	Kerosene											
	Pyrethrum 3.6 cc.											
	(Atomized)											
6—7	Kerosene			50.2%	26.6%	22.8%						33.2%
	Pyrethrum 10.0 cc.											
	(Atomized)											
9—12	Pyrethrum "A" 1.0%			35.5%	11.8%	13.8%						20.4%
	(Atomized)											
15—17	Pyrethrum dust			25.2%	24.0%	43.0%	29.0%					30.3%
19—21	Control ..	..	..	30.4%	30.8%	24.2%						28.5%
22—27	Pyrethrum "A" 1.0%			56.8%	32.6%	50.4%	46.0%	37.0%	40.8%	35.6%	56.4%	44.5%
28—30	Control ..	..	..	20.2%	18.2%	14.6%	16.8%	23.0%	33.2%	41.6%	30.4%	24.8%
31—36	Derris Wash 5 lbs.			50.2%	37.8%	47.4%	48.6%	36.8%	50.4%	44.8%	39.6%	44.5%
37—42	Derris Wash 2½ lbs.			6.2%	2.8%	1.8%	4.8%	2.0%	2.0%	8.4%	10.0%	4.8%
43—48	Pyrethrum "A" 0.25%			2.8%	3.4%	3.6%	3.6%	4.8%	4.0%	8.4%	9.6%	5.0%
49—54	Derris Emulsion			38.4%	24.6%	40.6%	26.2%					32.4%
55—60	Control ..	..	..	20.0%	40.6%	31.6%	39.6%					34.5%
61—66	Pyrethrum "C" 0.25%			42.5%	55.4%	63.6%	53.2%	57.5%	48.0%	43.6%	30.8%	49.5%
67—72	Pyrethrum "C" 1.0%			14.0%	37.8%	40.8%	22.8%	32.0%	40.1%	34.8%	22.8%	31.3%
73—77	Control ..	..	..	6.9%	8.8%	13.0%	19.6%	13.0%	22.4%	36.0%	28.4%	17.7%
79—82	Derris Dust			—	21.0%	36.2%	42.8%	42.4%	37.2%	2.0%	8.8%	34.9%
				3.3%	1.8%	1.0%	1.8%	1.2%	2.0%	2.0%		2.7%

The aqueous washes did not cause any damage to the foliage, flowers or berries, despite their application during the full heat of the sun. The dust adhered to the berries and the carrier filled the spaces between the drupes.

The atomized kerosene caused a characteristic stiffening of the foliage, although the leaves remained green in colour and a good crop of berries was produced. All the pickings were tainted and tasted strongly of kerosene, proving that the spraying was complete. It is probable that the atomized vapour penetrated between the drupes of the berries and before it could volatilize the drupes developed and closed in the kerosene. It was noted that the last picking was only slightly tainted. Nearly three weeks elapsed between the last application and the first pickings, and during this period there were many days of intense heat (hot sun).

TRIAL CENTRE II. LONG ASHTON PLANTATIONS.

The raspberry variety trial plots were sprayed with three different washes, viz., (1) Pyrethrum "A" at 1.0 per cent, (2) Pyrethrum "C" at 0.25 per cent and (3) Derris soap suspension at $2\frac{1}{2}$ lbs. per 100 gallons of water. This provided an opportunity of comparing the control obtained with the three washes. The berries from two varieties of raspberries, Lloyd George and Duke of Cornwall, were examined. Each of these varieties were grown in six units of three long rows, and each unit consisted of twenty-one stools. The intensity of the infestation by the beetles had been approximately the same on each unit.

TABLE II.

Trial II. Raspberries. Comparative Percentage Infestation.

Date of Picking.	Treatment.					
	Pyrethrum "A" 0.25%		Pyrethrum "C" 1.0%		Derris Soap Suspension.	
Variety	Lloyd George.	Duke of Cornwall.	Lloyd George.	Duke of Cornwall.	Lloyd George.	Duke of Cornwall.
11.7.32	24.5	20.0	14.7	6.6	5.7	2.1
13.7.32	11.6	9.6	12.1	4.5	1.4	3.6
15.7.32	23.1	22.2	12.6	2.4	3.0	0.8
18.7.32	32.9	38.5	18.7	17.6	5.2	6.1
20.7.32	39.9	37.7	33.6	10.6	5.2	1.0
22.7.32	12.3	21.0	17.9	11.1	4.4	0.6
25.7.32	14.9	25.3	21.1	14.4	3.9	1.2
27.7.32	17.3	41.5	17.6	12.9	4.8	2.0
29.7.32	12.6	43.8	41.6	19.3	12.8	2.2
3.8.32	60.7	36.6	35.8	11.3	8.1	20.7
Average	25.0	29.6	22.6	11.1	5.5	4.0

Two applications of the washes were made, the first on June 18th, nine days after one-third of the blossom was open, and a second on June 23rd, ten days after all the blossom was open. The majority of the beetles suddenly disappeared on June 16th and at the time and after the first spraying very few could be found. Picking commenced on July 11th and random samples of 500 berries from each treatment on the two varieties of raspberries were examined, giving a total of 28,000 berries for all the counts. The results are recorded in Table II on previous page.

The derris soap suspension wash provided the best control. The pyrethrum emulsions at two different concentrations provided different results on the two varieties of raspberries. In the case of Lloyd George the results were approximately the same, whereas in the case of Duke of Cornwall the wash at 1.0 per cent gave superior results to the weaker wash. This is probably due to the fact that the eggs on this variety were laid earlier and may have hatched within the duration of effective toxicity of the more concentrated wash (1).

The crop weights of the units of raspberries from which the counts were made were as follows :

TABLE III.

Variety	Treatment.					
	Pyrethrum "A" 0.25%		Pyrethrum "C" 1.0%		Derris Wash.	
	Lloyd George.	Duke of Cornwall.	Lloyd George.	Duke of Cornwall.	Lloyd George.	Duke of Cornwall.
No. of fruiting canes	1,377	1,355	1,205	1,078	1,352	1,505
Crop weight in lbs.	204	180	179	117	193	149
Average infestation	25.0%	29.5%	22.6%	11.0%	5.3%	3.9%

It is evident from the above crop weights that a decrease in larval infestation was not reflected by an increase in crop, in fact the greatest crop weight was obtained from the units showing the highest infestation. It was evident from observations that adult damage during the 1932 season was responsible for an appreciable loss of crop (3).

TRIAL III. LOGANBERRY PLANTATION AT STOURTON, WORCESTER.

Lay-out.

The trial was carried out on 7 acres of loganberries, consisting of thirty-nine rows, 160 yards long, planted in 1929, and thirty rows, 160-200 yards long, planted in 1930. The rows were 6 feet apart.

Eight different treatments were tried, principally with the object of ascertaining :—

- (1) The control obtained by the application of a derris dust when the adult beetles were present in numbers. The last application was made before many of the flowers were opening and therefore before many eggs were laid.
- (2) The control of larvae obtained by means of derris soap suspension washes.
- (3) The control of larvae obtained with a pyrethrum emulsion used at concentrations representing 0·25 and 1·0 per cent of the pyrethrum flowers.

The treatments were applied as follows :—

Rows 1-42	Derris Dust. Three applications. May 17th, 25th and June 3rd.
43*	Buffer Control.
44-47	Pyrethrum Emulsion " A " 1·0 per cent. Two applications. June 20th-21st and June 29th-30th.
48-49	Pyrethrum Emulsion " B." Two applications.
50-51	Derris 5 lbs. per 100 gallons water (0·0086 per cent rotenone). Two applications.
52-53	Derris 2½ lbs. per 100 gallons water (0·0043 per cent rotenone). Two applications.
54-55	Control.
56-57	Pyrethrum Emulsion " A " 0·25 per cent. Two applications.
58-60	Pyrethrum Emulsion " C " 0·25 per cent. Two applications.
61-62	Pyrethrum Dust I. One application. June 20th.
63-68	Pyrethrum Emulsion " B." One application.
69	Control.

Application of the Dusts and Washes.

The beetles appeared on the loganberries before the flowers were open and collected in large numbers on the unopened flower buds, the infestation being most severe, before the application of the derris dust, on rows Nos. 1-39. The beetles first appeared in numbers on May 17th and at this date the first application of derris dust was made. Shortly after this date the infestation increased

* The row No. 43 was intended as a buffer row and row No. 44 as a Control. Owing to a misunderstanding pyrethrum emulsion was applied to row No. 44, therefore row No. 43 was taken as a buffer control. It is probable that the infestation obtained was slightly lower than it would normally have been, on account of dust drift from row No. 42. In order to reduce the error all the fruit was collected from the side less likely to have received the dust drift.

and reached a maximum between May 24th and June 3rd. During this period two dustings were given, i.e. on May 27th and June 3rd. Large numbers of the beetles were killed and in addition the dust caused a wider distribution of the beetles and increased the infestation on the remainder of the plantation, particularly of rows Nos. 40-69. Approximately the first third of the flowers was over on June 7th-8th and full flowering was over on June 16th-17th. The bulk of the flowers opened during a short period and petal fall took place very rapidly.

The washes and the pyrethrum dust were applied on the same dates. The first applications were made on June 20th and 21st and at this period it was difficult to find any beetles but numerous larvae and eggs were present. The second applications were made on June 29th-30th.

The wet washes were applied in the heat of the sun and caused some scorch of the foliage on the fruiting canes, but the damage did not appear to interfere with the production of the crop. The foliage is believed to have been rendered more susceptible to scorch damage by some soil condition. On other plantations only very slight damage occurred, and it has been found that loganberry foliage is more subject to damage than that of the raspberry. No damage was done to the new shoots. The weather during, between and after the applications was fine.

Results.

The berries were collected by the same pickers who were trained to collect random samples. From each treated plot six 1 lb. punnets were obtained and approximately 500-800 berries were examined at each count of each plot. A total of 45,000 berries was examined.

The results are recorded in Table IV.

The best results were obtained with the derris washes. These were equally satisfactory and the high control of the larval damage was maintained throughout the picking season. The results obtained by dusting the beetles with the derris dust appeared to be good and it is important to remember that the assemblance of the beetles in large numbers on the flower buds prior to the flowers opening greatly enhanced the chances of killing the beetles. Moreover, at this experimental centre, it was evident that numbers of the beetles were repelled by the dust and distributed themselves over the remainder of the plantation at the period of oviposition. It is exceedingly difficult to evaluate accurately the control obtained by dusting or spraying against insects that are able to fly; the dust or liquid may not in itself be sufficiently toxic to kill the insects but it may cause them to prefer the untreated plots and therefore the attack on the latter is greater than it normally would have been.

TABLE IV.
Trial III. Loganberries, Stourton, Worcester. Percentage Infestation.

Date and Number of Picking.		2	3	4	5	6	7	8	13	Average Percentage Infestation.
Row No.	Treatment.	12.7.32	15.7.32	18.7.32	20.7.32	22.7.32	25.7.32	29.7.32	11.8.32	
1-42	Derris Dust ..	1.3	4.4	9.1	9.0	—	9.9	20.0	11.7	9.3
43	Control (Buffer) ..	39.3	29.1	35.4	37.1	23.8	20.3	37.4	16.5	29.9
44-47	Pyrethrum "A" 1.0% ..	8.2	15.1	18.2	15.1	15.1	10.3	26.3	10.1	14.8
48-49	Pyrethrum "B" ..	15.5	22.7	33.3	35.3	26.0	44.3	—	—	29.5
50-51	Derris Wash 5 lbs. ..	4.0	1.6	1.1	3.3	4.5	2.9	2.1	—	2.8
52-53	Derris Wash 2½ lbs. ..	0.5	1.6	4.5	2.9	3.3	7.4	1.6	—	3.3
54-55	Control ..	50.0	33.8	52.9	39.1	32.5	42.4	16.2	4.8	30.1
56-57	Pyrethrum "A" 0.25% ..	19.0	24.4	42.4	30.6	26.5	—	16.1	21.9	26.5
58-60	Pyrethrum "C" ..	12.6	31.3	31.0	34.3	28.3	—	—	—	31.1
61-62	Pyrethrum Dust I. ..	49.5	60.8	—	44.2	—	—	—	—	51.5
69	Control ..	53.4	57.0	55.7	59.8	39.0	45.5	—	—	51.7

A commercial control was obtained with the 1·0 per cent Pyrethrum Emulsion "A," but the results were inferior to those obtained with the derris wash. Further the cost of 100 gallons of this pyrethrum would be about 26s. compared to 7s. 6d. for the derris. Lower concentrations of the pyrethrum washes gave poor results. The pyrethrum dust was applied by the grower and only one application was made; the carrier, kaolin, as a result of the combined action of dew and sun, set hard between the drupes and could not be removed. No control was obtained.

The crop weights obtained from the derris wash treated plots were 35 per cent greater than those on the control and other plots heavily infested with larvae.

General Review of the Results and Recommendations.

It is evident from a consideration of the results at the three trial centres that the principal control of the pest is obtained by killing the larvae, and during most seasons when the oviposition period is prolonged, this mode of control will provide the most consistent results. However, in some seasons, such as that of 1932, when the beetles assemble in large numbers on the unopened and opening flowers, it is advisable to reduce their numbers to avoid a loss of flower buds and berries (3) by the application of a derris dust.* A pyrethrum emulsion will provide an equally good kill of the beetles but the cost of application would be greater, and moreover the duration of toxicity of the pyrethrum emulsion at 1·0 or 0·25 per cent would be shorter than that of the derris. It will be inadvisable to depend on controlling the pest by killing the beetles only. At least one and preferably two applications of a derris wash at a concentration of not less than 0·0043% rotenone should be applied.

The best periods of application appear to be most suitably expressed in days after flowering. The first application should be made approximately ten to twelve days after one-third of the total flower buds are fully open, and a second application ten days after full blossom period.

It is evident from the results obtained with the various pyrethrum emulsions and kerosene pyrethrum, containing different quantities of the toxic principles, that the higher the concentration the better the results. It was found that the lower concentration gave an immediate kill of the larvae and in view of the complete wetting of the berries obtained with the washes very few of the larvae could escape death. The eggs were not killed. Therefore the length of duration of the toxicity of the spray or dust was of the greatest importance in order to kill the larvae that hatched from the eggs after the date of application. It appears from the results that the washes with a greater content of toxic principles

* A rotenone content of 0·18% is recommended until a lower concentration is proven to give satisfactory results.

of pyrethrum owed their superior results to the longer duration of the effective toxicity. The excellent results obtained with the derris soap suspension was due to this duration of toxicity. It must be remembered that the weather at, between and after the applications of the derris was fine and dry, and it remains to be seen if equally good results can be obtained in a wet season, when there is more chance of the derris being washed off the berries.

SUMMARY.

1. The results indicate that the degree of control of the larvae depends largely on the duration of toxicity of the insecticide after application. Pyrethrum washes representing a concentration of 0.25 per cent of the flowers did not provide a control. A 1.0 per cent wash provided a higher control than the 0.25 per cent concentration, but the results were inferior to those obtained with a much cheaper derris wash.

2. Two applications of a derris wash containing less than 0.004 per cent rotenone provided a high control of the larvae. The first application was made ten days after approximately the first third of the flower buds had opened and a second application ten days after the full flowering period. No further increase in control resulted by using a wash of a higher concentration than 0.004 per cent rotenone.

3. In those seasons in which the beetles cluster in large numbers on the unopened and just opening flower buds, the application of a derris dust (containing 0.18 per cent rotenone) is effective in killing large numbers of the beetles. The dusting should be followed by at least one application of a derris wash in order to kill the larvae.

4. Atomized pyrethrum preparations were tested as a means of killing the larvae but the results were unsatisfactory.

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at Long Ashton, whilst Mr. A. Wilkins, Laboratory Assistant, rendered similar assistance at Worcester. Finally, sincere thanks are due to the Technical Products Ltd. for the supply of the carefully prepared Pyrethrum "A" Emulsion, kerosenes and pyrethrum extract.

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THE ADULT RASPBERRY BEETLE AS A CAUSE OF SERIOUS BLOSSOM INJURY

By H. G. H. KEARNS and C. L. WALTON

INTRODUCTION.

THE larva of the Raspberry Beetle (*Byturus tomentosus*) is the most serious pest of the raspberry and loganberry and is responsible for the majority of the damage to the berries. In some seasons the crop may be reduced also by the attacks of the adult beetles and the following types of injury have been recorded.

Lees (1) says " They feed on the tissue of the base of the flower, the nectaries being probably especially attractive. As they feed they destroy the base of the stamens but otherwise do not do much direct damage."

Warburton (2) states that " They pierce buds to prevent many of them from developing at all. Later they attack open blooms and feed upon stamens and petals. Much harm is done in these early stages."

Walton (3) quotes both the above and adds, " After a detailed examination of some 18,000 fruits I am inclined to the view that the injury caused by the adult beetles at this stage is often by no means negligible," and describes " scars left on the disc and base of the receptacle . . . the basal and peripheral drupes of such flowers frequently remaining shrivelled and green, causing the fruits to be imperfect and to some extent malformed . . . it seems highly probable that such injuries may be caused by the feeding habits of the adult beetle."

The adult damage was severe in the 1932 season and was the subject of a number of enquiries. The attacks in the Bristol Province were rendered more conspicuous by the appearance of the beetles in large numbers on the nearly mature and opening flower buds which were later than usual in opening. An attack on the raspberries in the Long Ashton plantations provided an excellent opportunity of observing carefully the nature and extent of the damage caused by the beetles.

THE ATTACK AT LONG ASHTON.

Adult beetles are usually on the wing in numbers for some time prior to the opening of the flowers of loganberry and raspberry and then frequent other flowers, notably those of the apple and pear (Lees (1) and Walton (3)). They may generally be obtained in large quantity from these sources.

For the attack under consideration the damage occurred on various varieties and on several parts of the plantations, but the worst case was on a 2 acre plot

of Baumforth "A" raspberry. This plot is narrow and for a considerable part of its length only separated by a distance of 9 yards from an apple plantation. The varieties of apples nearest to the raspberries were Lane's Prince Albert, Stirling Castle and Allington Pippin.

The raspberry flowers were unusually late in opening and the apple blossom, for the most part, had fallen before any considerable number opened. The majority of the petals of the apple fell on June 1st and just prior to and immediately after this date the beetles migrated from the apples to the raspberries and reached their maximum concentration on the terminal shoots by June 8th, when only a few of the flowers were open. After this date the flowers opened rapidly and the beetles became more evenly distributed and fed within the flowers.

On June 14th a random count of 1,000 terminal raspberry buds and flowers was made. Of the count approximately 75 per cent consisted of buds and 25 per cent open flowers, and of these 52.8 per cent were injured.

On July 13th, just before the second picking of fruit took place, a random count of 1,000 berries on the top 18 in. of 115 yards run of canes was made, and it was found that 29.7 per cent of the berries were seriously malformed.

The injuries could be classified as follows :

1. The peduncle of young buds bitten through with consequent loss of the bud. This damage occurred more especially in the centre of the clusters.
2. The unopened bud eaten into or eaten away (damage occurred in all degrees of severity).
3. Stamens and nectaries of the open flower eaten away.
4. The entire flower destroyed with the exception of the sepals.
5. Berries just set eaten away in varying degrees, which interfered with or prevented the normal development of the drupes.

These conditions are illustrated by the accompanying photographs. Fig. 1 shows damaged nectaries which have become brown in colour and small, malformed fruits resulting from beetle attack and forms a contrast with the uninjured spray of Fig. 2.

In very many cases the injured buds failed altogether to develop, and shrivelled up.

The extent of this attack was reflected in the crop picked, the plot in question yielding two pickings less than another plot of the same variety in another part of the plantations, where injuries were less severe.

It was evident from observations made at Long Ashton and in other plantations that the crop weights in 1932 were reduced more by the extent of the adult damage than that caused by the larvae. The adult damage is more



FIG. 1. Adult beetle damage. Many of the berries have failed to develop as a result of the beetles attacking the open flowers. The damaged nectaries appear as a dark ring around the base of the receptacle.

FIG. 2. Unattacked Baumforth "A" berries, in which the drupes have developed normally.

likely to assume serious proportions in seasons in which the climatic conditions favour the assemblance of large numbers of beetles on the raspberries and loganberries before the flowers open. Further observations on the significance of the clustering of the beetles on the unopened flower buds will be referred to in a communication (4) on the control of the Raspberry Beetle.

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THE STRAWBERRY "YELLOW-EDGE" DISEASE

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I. GENERAL INTRODUCTION.

IN 1931 and 1932 a series of experiments was carried out to investigate by the method of grafting a suspected degeneration disease of the virus type in the *Royal Sovereign* strawberry. An account of the inception of this investigation and of the methods of grafting tested has already appeared (12). Evidence of virus transmission in the 1931 experiment (designed primarily to test various methods of grafting) was of a tentative nature owing to a heavy general infestation of the "healthy" plants and runners with mite (*Tarsonemus fragariae*) subsequently to making the grafts. An experiment in confirmation carried out in the following season (using one standard method of grafting throughout) yielded positive results indicating the existence in this country of a transmissible virus-disease of strawberry plants which is clearly, apart from the direct action of associated mite and insect pests, a potent cause of the degeneration of plantations of the *Royal Sovereign* variety (and probably of other varieties) in Kent and, it would appear, elsewhere in the country.

II. LITERATURE.

The majority of recent workers on degeneration diseases of the strawberry on the American Continent regard the main cause as being inherent in the plant itself and of a virus nature.

The first disease of this type to be identified was *Strawberry Xanthosis*, originally known as Strawberry "Yellows" (see p. 72). The symptoms of this disease as described by Plakidas (14, 15) closely resemble those of the disease to be described in the present paper. The close similarity, also, of the symptoms of *Xanthosis* and of *Aphis Plant* in this country has been noted by Briton-Jones and Staniland (7). Plakidas was able to transmit the disease using an aphid (*Myzus fragaefolii*) as vector (15).

More recently other forms of degeneration associated with symptoms distinct from those of *Xanthosis* have been described, namely *Strawberry Dwarf* or *Crimp* (16, 8, 9), "Yellows" (17),* "Mosaic" (5, 6), *Witches Broom* (22), and

* See p. 72. Distinct from *Xanthosis* and found in Northern and Eastern States of Canada.

Crinkle (23). With the possible exception of Dwarf, these diseases are regarded as virus-diseases but up to the present no conclusive transmission experiments in confirmation have been described. Strawberry Dwarf is regarded by Plakidas (16) as a virus disease, but more recently Brooks (8, 9) maintains that the symptoms are the direct result of the infestation of buds by an eelworm.

In this country a considerable literature dealing with the causes of strawberry degeneration has arisen since the resuscitation of the industry after the Great War and the following "diseases" have been identified (3, 13): *Cauliflower* (? Eelworm), *Red Plant* (? Eelworm), *Patch* (defective soil conditions), "*Miffy*" (Crown damage), *Small-leaf* (water-logging, desiccation, cultivation damage), *Aphis-plant* (*Capitophorus fragariae*) and *Mite-plant* (*Tarsonemus fragariae*). With the exception of *Aphis-plant* and *Mite-plant* the assignment of the main causal factor of these diseases is purely tentative, being hitherto based exclusively on association and observation, and they are therefore regarded at present as convenient symptom groups (often grading into each other) rather than as specific diseases. On the other hand the symptoms of *Aphis-plant* and *Mite-plant* have been reproduced by artificial infestation under controlled conditions (7, 13).

The possibility that plants showing the symptoms of the above diseases may contain an additional causal factor inherent in and distributed throughout the plant system itself (e.g. a virus), has been suspected (4, 7, 20, 21). The existence of a disease of this nature is further suggested by the very common insistence on the necessity for a careful selection of "healthy" vigorous plants for runner beds and on the subsequent elimination of all degenerate plants (2, 10, 18, 19, 24). In the latter part of 1930 certain local cases of a serious degeneration of the Royal Sovereign strawberry (see p. 58) were brought to the notice of the present writer, in which the degree of mite and insect infestation of the plants was not sufficiently serious to account for the observed failure, and it seemed probable that another factor was present, the symptoms of which were masked by that infestation. Massee, also, in his direct mite-infestation experiments found that although after applying control measures against the mite a proportion of the infested plants recovered, other comparable plants in the same series apparently infested to the same degree and exhibiting similar symptoms, continued to degenerate and eventually died. Repeated examinations of such plants failed to reveal the presence of a visible pathogen, and indicated strongly the need of a method for testing for a virus-disease which would render the use of possible mite and insect vectors unnecessary. Methods of grafting, an account of which has already appeared (12), were therefore devised, and the subsequent experiments in their application will now be described.

III. EXPERIMENTS IN TRANSMISSION BY GRAFTING.

In the description of these experiments the following conventions will be adopted. Plants and runners suspected of infection with the disease will be referred to as "yellow-edge" or "Y" plants, and those thought to be free from infection (although possibly infested with mite or insects) will be called "healthy" or "H" plants. A grafted unit of parent-plants and runners consisting of a healthy plant runner-grafted to a "yellow-edge" plant will be designated an H/Y unit (Text, Fig. 1). The corresponding "control" consisting of a "healthy" parent-plant runner-grafted to a "healthy" plant will be called an H/H unit (Text, Fig. 2). The convention with regard to the use of the term "stolon" and "runner" adopted in the previous paper (12, p. 37) will be adhered to.

A. MATERIAL. ("Yellow-edge" and "Healthy" parent-plants.)

The two experiments (carried out in 1931 and 1932 respectively) were limited to an investigation of the disease as it occurs on the variety *Royal Sovereign*.

The plants were grown in pots, and the experiments were carried out in a cool greenhouse throughout. Every precaution was taken to prevent the "yellow-edge" plants or their runners from coming into contact with the "healthy" plants except at the point of graft union. Until the time of grafting, all the "yellow-edge" and healthy plants were kept in separate compartments of the greenhouse.

1. "Yellow-edge" Parent-Plants.

The "yellow-edge" plants used as parent sources of infection in both the experiments were selected from some eighty suspected plants collected from the Swanley district* and from the strain-trial plots at East Malling, during November and December, 1930. The former consisted mainly of runners (from maiden plants) potted in June 1930 for forcing, and in addition a few sterile two-year plants and their runners; the latter, of three-year-old plants in an advanced condition of degeneration. At the time of selection these plants had a "flat" appearance, and were clearly lacking in normal vigour of growth. In addition a proportion of the leaves of some of them showed chlorotic margins, but this differentiating symptom was not common to all of them and in no case was it very clearly defined.

Towards the end of April, 1931, and in spite of a rigorous application of precautionary control measures (see p. 60), all the plants in this collection developed symptoms of mite infestation with the result that from this time until

* This initial collection was made by Mr. W. Corbett, Advisory officer in Glasshouse Work and Market Gardening for Kent, whose valuable assistance in the early stages of the investigations has been acknowledged elsewhere (12, p. 35).

August no distinguishing symptoms, apart from an obvious lack of vigour and cropping power, could be detected on any of them.

In August, however, a very striking development of symptoms distinct from those of direct mite-injury were apparent on some of the less severely infested plants. These symptoms, which are described in detail below (see p. 69), consisted of a general dwarfing of the leaves produced at this time of the season, accompanied by a chlorosis localized in the marginal region, a curling and a distortion of the constituent leaflets in varying degree. The petioles of such leaves were short and abnormally stout, and were lacking in the normal red pigmentation (see Plate IV, Fig. 1). As the season progressed and these symptoms developed, the general appearance of the plants became increasingly distinct from the comparable "healthy" plants (Plate IV, Fig. 2).

In the 1932 season these symptoms could be more easily recognized owing to the more effective control of mite, but again their manifestation was not complete until late in the season. A detailed survey of the above collection of potted type "yellow-edge" plants was made on August 12th when it was found that a large number of plants known by previous examinations to be infected with the disease had not by then developed any of the leaf-symptoms. On October 13th a final survey was carried out when it was found that on such plants the symptoms had become fully apparent.

2. *Healthy Parent-Plants.*

Of the two entirely distinct sets of "healthy" plants used in the 1931 and the 1932 experiments, that used in the former consisted of a non-clonal collection of *Royal Sovereign* runners potted up in the Autumn of 1930. These plants (originally intended for fungal inoculations) were specially selected for their vigour and apparent healthy and mite-free condition. They remained apparently mite-free until the grafting operations had been started but on May 19th incipient symptoms of mite attack were noted on some of the plants and subsequently all the plants were found to be infested, and that in spite of the rigorous measures applied for their control (see p. 60). This infestation was a very serious handicap to the experiment on the issue of virus-transmission.

In 1932 a single clone of *Royal Sovereign* runners constituted the "healthy" side of the experiment. This was derived from a plant specially selected from a vigorous strain for its outstanding vigour, health, and freedom from mite and insect pests. The progeny of this plant were carefully examined in the Autumn of 1931 and were found to be uniformly healthy in appearance. The runners were potted in December, 1931, and subsequently kept in a cool greenhouse until the conclusion of the experiment.

Throughout the experiment these plants were remarkable for their general uniform health, vigour of growth, and prolific runner production. A large

proportion of them remained free from mite infestation, and no single case of extraneous infection with "yellow-edge" occurred.

3. *Mite and Insect Control.*

From the inception of these experiments Mr. A. M. Massee has kept all the "yellow-edge" and "healthy" plants and runners under detailed observation from the point of view of mite and insect infestation, and the elaborate programme of control measures applied has been carried out under his direction.

In April, 1931, symptoms of mite infestation appeared on many of the "healthy" and "yellow-edge" parent-plants. Control measures were applied and the spread of infestation was checked until June. Thereafter the spraying and observational work was not continued so rigidly and as a result the mites became firmly established, and being under greenhouse conditions they bred very rapidly and destroyed a large proportion of the runners. Once the attack had become very severe, mite control was impossible because the plants were in such a weak state that any form of spray fluid damaged or killed the unhealthy growths.

A more effective control of mite was obtained in 1932 when only a small proportion of the parent-plants and their runners developed symptoms of infestation. In the case of the "yellow-edge" parent-plants this was clearly the result of the cumulative effect of the spray treatments initiated the previous year. In the case of the healthy clone it was probably due partly to a smaller proportion of cases of original infestation and partly to an improved control programme the following summary of which has been kindly supplied by Mr. Massee.

The plants were dipped in lime-sulphur or white oil before being potted up. After potting they were examined regularly (at least three times a week) and were sprayed when necessary. Each plant received a minimum of ten routine sprayings with either lime-sulphur or white oil (+ Agral 1 or gelatine). In addition any plants showing signs of mite damage were treated immediately. Some of the plants were thus treated as often as twenty times during the season.

In no instance was the mite allowed to get established. Directly any mites were detected on a plant that plant was isolated until such time as the mite had been controlled.

The established runners were treated even more rigorously than the parent-plants. They were examined individually at weekly intervals by means of a binocular microscope and if any trace of mite infestation was detected the infested plant was dipped in white oil or sprayed with lime-sulphur. A suspected infestation during August necessitated spraying with lime-sulphur no less than four times in one week. This treatment did not affect the plants, but controlled the pest before it did any material harm.

Latterly in 1932 infested plants were subjected to the hot-water treatment in order to eradicate the last traces of mite.

In addition to mite a careful inspection of the plants for aphid (*Capitophorus fragariae*) was made from time to time and nicotine was frequently introduced into the sprays as a precaution against attack. In no instance, however, during the course of the two years' work was aphid detected on any of the plants used.

B. THE EXPERIMENTS.

1. *The 1931 Experiment.*

(a) *Methods.*—The methods of grafting used throughout this experiment have already been described (12). The scheme adopted was the simplest possible, the grafted *runner* of an H/Y or H/H (control) graft being compared with the "yellow-edge" and "healthy" *parent-plants*, not with "control-runners" taken from these plants, as in the 1932 experiment, i.e. as shown in text, Figs. 1 and 2, but omitting runners B, C and D. The possible passage of mites from the diseased parent-plant to the healthy runner was prevented by banding the stolon between the union and the grafted runner with vaseline. This grease band will be referred to hereafter as a "mite-trap."

(b) *Results.*—Owing to the severe infestation of both "healthy" and "yellow-edge" plants with mite, the results from the point of view of determining possible virus transmission were seriously obscured on the majority of the grafts.

In spite of such infestation, however, "yellow-edge" symptoms were clearly distinguishable in early August on the grafted (A) runners of two out of the total six successful H/Y grafts (Plate I, Fig. 2). These runners approximated in appearance very closely with the "yellow-edge" parent-plants upon which they were grafted rather than with the healthy parent-plants from which they were derived. The corresponding runners of the remaining four successful H/Y grafts became so seriously infested with mite as to mask any "yellow-edge" symptoms that might have been present, but degenerated rapidly, and died shortly after grafting. On the other hand no trace of "yellow-edge" symptoms could be detected on any of the grafted (A) runners of the four successful H/H (control) grafts and in spite of mite infestation these runners grew away with moderate vigour after grafting.

2. *The 1932 Experiment.*

A further experiment was carried out in 1932 to confirm the above results. The following modifications were adopted. (1) The healthy batch of plants used consisted of a clone; (2) one method of grafting was used throughout; (3) each graft was controlled completely by taking a comparable ungrafted runner from each of the parent-plants. Each grafted runner was thus compared with a

perfectly comparable "control-runner" from the same plant, not with the parent-plant.

(a) *Methods.* (i) *Grafting.*—All the parent-plants used in the experiment, "healthy" and "yellow-edge," were deblossomed. Each plant of the healthy clone was limited to four stolons per plant and each stolon was stopped at the first runner. When a stolon from a diseased or "healthy" parent-plant had pushed out from 3 to 6 inches it was banded with vaseline about 1 inch below the bud and later it was attached with lead wire* to a split cane stake in order to prevent it from coming in contact with other plants or runners, or with the bench. In this way each runner was completely isolated from its earliest stages of growth until the completion of the experiment. Grafting operations were commenced on June 8th and the final successful grafts were made on July 7th. The method used, with one or two exceptions, was a modification of the "*Inarching Method 2,*" previously described (12, p. 39). By using this method both the runners on the two stolons to be grafted were retained. As it was essential, however, that these runners should be kept separated after grafting, the graft union was made at a distance of approximately 6 inches from the runner-tip instead of just behind the runner-tip as originally figured. Having carried out a graft, the two parent-plants were placed out of contact on the greenhouse bench, and the grafted runners separated and supported in an isolated position by hanging them with lead wire supports to a specially constructed wire-netting frame fixed above the bench (Plate I, Fig. 1). Care was taken immediately after attachment to interpose a mite-trap on the stolon between each runner and the union and point of attachment to the frame.

From fourteen to twenty-one days after grafting the raffia binding was removed and the graft examined, and it was invariably found that union had taken place after a lapse of twenty-one days. The two grafted runners, still attached to the parent-plants, were then potted, and about one week afterwards the stolon from one of the parent-plants was severed, leaving the two runners attached by one stolon to one of the parents. In the case of the H/Y grafts the "yellow-edge" parent was detached first in order that if any degeneration of the runners subsequently took place it should not be due to both runners having been left attached to a degenerate plant. As soon as it was ascertained that the runners were well rooted they were severed from each other and from the remaining parent-plant. In some cases the severance of one of the parent-plants was carried out *before* potting the runners, but it was found that in such cases the runners almost invariably flagged afterwards. This flagging was not an indication of a failure of the

* 22 gauge lead-wire was used. Owing to its extreme pliability and the ease with which it is divided without a wire-cutter it was of the greatest value for the suspension and manipulation of runners before and after grafting.

graft, but that the water supply to the two actively transpiring runners through a single stolon was inadequate. It was easy to determine whether union had taken place simply by an inspection of the graft itself.

Of the total of twenty-seven grafts attempted twenty-two were successful (81 per cent). The failures and doubtful unions all occurred on H/Y grafts. This is not surprising because, as already mentioned, the very small number of runners produced by the diseased plants necessitated using every such runner for grafting and the majority of them being very dwarf and tenuous, and all the runners from the healthy plants stout and vigorous, the grafting process was extremely precarious and difficult. In spite of these difficulties the 70 per cent successes obtained with H/Y grafts, indicates the reliability of the method adopted.

(ii) *The Plan of the Experiment.*—The whole experiment was subdivided into a number of self-contained and controlled "graft-units," each unit consisting of two runners connected by the grafting process, and one or two "control-runners" taken directly from one or both of the parent-plants. The plan of

FIG. 1.

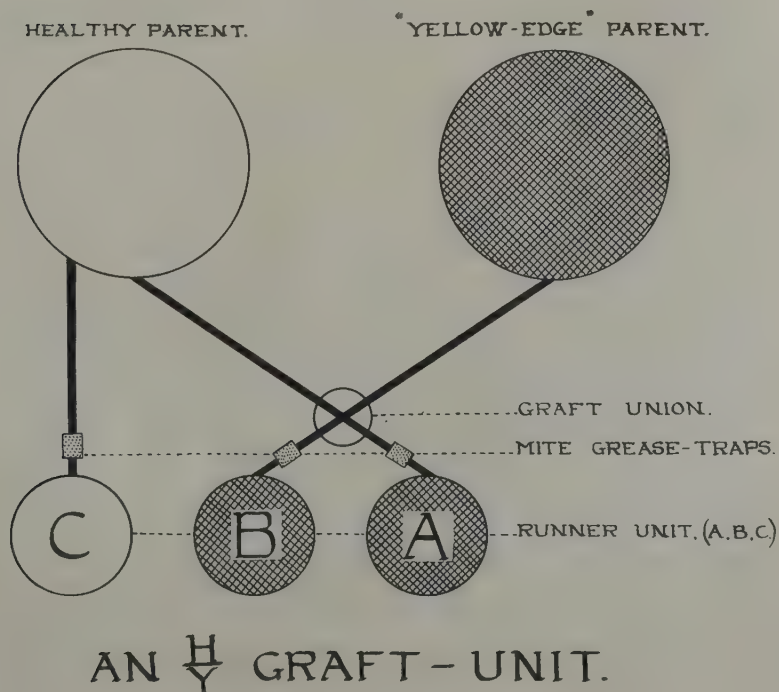
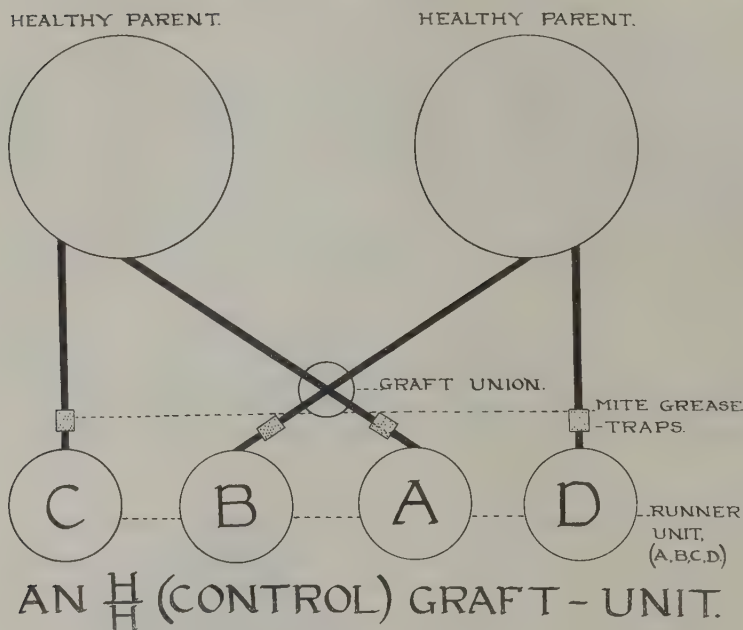


FIG. 2.



these units and the convention adopted in the designation of the runners in the units is shown in text figs. 1 and 2.

In the H/Y units no control-runners were taken from the "Y" parents owing to the shortage of runners from these plants and the necessity of using every such runner for grafting. It was thought that runner B would act as an adequate control in this respect. Each H/Y runner-unit, therefore, consisted of three runners (A, B and C), and each H/H control-unit consisted of four runners (A, B, C and D). From the time of grafting each set of runners was kept under identical external conditions, each runner being transferred to larger pots as its vigour of growth demanded. An examination and comparison of the text figures will make it clear that runners A and C in any unit were derived from the same "healthy" parent-plant, the only difference in treatment being that runner A was connected by grafting for a maximum period of four weeks to another plant ("healthy" or "yellow-edge") whereas runner C was taken directly from the "H" parent-plant. Any direct check to runner A due simply to the grafting operation could be assessed by comparing runners A and C in the H/H units. If no such check could be detected, any difference in vigour between runners A

and C in the H/Y units could only be due to some disease-principle present in the "yellow-edge" parent and transmitted to A through the graft union.

(b) *Results*.—From the time of setting of a graft, detailed observations were made on each runner in the unit, the appearance of any abnormal symptom being immediately noted. On September 14th and October 14th series of records were taken on all the runners throughout the experiment. These data included a determination of the spread* of each runner. On the latter date records were also taken on each parent-plant.

The records made on each successful graft-unit in the H/H and H/Y series are summarized in Table I. The comparison of the A and C runners in each series provided a very striking contrast (Plates II and III). In the H/H series (units 11-20) the A and C runners (and the B and D runners) in each set approximated closely in marked vigour of growth, and in certain units the grafted (A or B) runner was more vigorous than the corresponding control from the same plant (C or D), e.g. units 11, 13, etc. This indicates that the check given to the growth of the runner by the process of grafting was sufficiently small to be negligible in comparing the vigour of grafted and control runners.

In the H/Y series (units 1-10) the behaviour of the A and B runners in each unit was in striking contrast to that of the control runner C (Plate II, Fig. 2, and Plate III). The latter, except in exceptional cases of heavy mite infestation, grew away vigorously from the time of potting and were comparable in vigour with the runners in the H/H series. The A and B runners on the other hand commenced to degenerate from the time of grafting. In some cases this degeneration was extremely rapid and the runners died shortly after potting and before the time of the general manifestation of leaf symptoms (September and October). In such cases no leaf symptoms were manifested. In the majority of units, however, the degeneration was less rapid and on a number of runners clear leaf symptoms corresponding to those shown by the original type "yellow-edge" parent-plants developed (Plate III, Fig. 2). It will be noticed that a greater number of A runners (from "healthy" parents) developed symptoms than B runners (from the "yellow-edge" parents). As, however, the "yellow-edge" parents in all such cases showed symptoms, this was clearly due to the fact that the growth of these runners ceased at an early stage and no new leaves were produced during the critical period of symptom-manifestation. That such runners were actually infected with the disease-principle was clear by their failure to grow, in spite of their freedom from mite.

Cases of mite infestation are indicated in the Table where its sporadic distribution can be seen. It will be noted that with one exception (unit 19)

* The mean of two measurements in cms. taken at right angles, of the horizontal leaf spread.

where death was due to severing accidentally the vascular strand while grafting, all the A runners in the H/H series which died subsequently to grafting were heavily infested with mites, and their death was almost certainly due to this cause alone. The runners in this series which were mite-infested but survived were noticeably stunted, and developed "yellow-leaf" symptoms which were distinguishable from the "yellow-edge" symptoms shown by similarly infested A runners in the H/Y series. In October mite-infested C and D runners in the H/H series and mite-infested A runners in the H/Y series were simultaneously subjected to the hot-water treatment and the mite destroyed. The subsequent growth of the former runners was completely normal and healthy whereas the latter continued to degenerate and to show the type of leaf symptoms characteristic of the suspected "yellow-edge" disease.

Even more striking than the transmission of the disease to the A runners in the H/Y units was its transmission from the B ("yellow-edge") runners to the "healthy" parent-plants. After the grafting was completed and the runners severed, all the "healthy" parent-plants from both series were put together on one bench in the greenhouse. Early in October some of these plants showed clear and unmistakable "yellow-edge" symptoms. On reference to the records it was found that every plant showing such symptoms was the "healthy" parent-plant of an H/Y graft unit. Wherever a "healthy" parent-plant in the H/Y series was not at this time showing definite "yellow-edge" symptoms a note appeared in the record of that particular unit stating either that the graft union was of doubtful success or that there was evidence that the supposed "yellow-edge" parent was not actually infected. The symptoms shown by these infected parent-plants in the H/Y series were more clearly defined than those shown by the drastically inhibited A runners. In no single case did a "healthy" parent-plant in the H/H series subsequently develop "yellow-edge" symptoms. Bearing in mind that all the parent-plants in the H/H and H/Y series constituted a single clone the parent-plant of which itself remained perfectly healthy, additional proof was thus provided that the "yellow-edge" symptoms were induced by an infective principle transmitted through the graft union from the "yellow-edge" parent-plants. That all the C runners in the H/Y series remained healthy, vigorous and comparable with the C runners in the H/H series throughout, indicated that they were severed before infection was able to reach them via the "healthy" parent-plants.

The above results are summarized in Table II. The figures for each series are based on the 10 units in that series appearing in Table I.

(c) *Conclusions.*—The general conclusion to be drawn from the two transmission experiments described above may be stated as follows. It has been

found possible, by bringing a runner derived from a healthy *Royal Sovereign* strawberry plant, into organic union (by grafting) with a degenerate plant of the same variety showing certain symptoms (to be summarized below), to induce in that runner, under conditions rigidly controlled to exclude the agency of mite and insects, a rapid degeneration associated with the same set of symptoms, and ultimately (in many cases during the season of grafting) culminating in its complete sterility and death. The possibility of the infection having been carried by mites in cases where the parent "yellow-edge" plant was mite infested was excluded by the mite grease-trap precaution described. In view of the "eelworm" hypothesis advanced by early workers in this country on Red Plant and more recently in America by Brooks and others in the case of "Strawberry Dwarf" (8, 9) the possible relation of *Aphelenchus fragariae* to the

TABLE II.

1932 Experiment. General Summary of Results.

Series.	Runner-Units (A, B, C, D).										Parent-plants.	
	% of "A" runners developing "yellow-edge" symptoms.	% of "A" runners dead before end of season.	% of "A" runners mite-infested.	Average "spread" of runners (cms.)								% of H parent-plants subsequently developing "Y" symptoms.
				including Mite-infested runners.				excluding Mite-infested runners.				
				A.	B.	C.	D.	A.	B.	C.	D.	
H/Y	70	50	30	10	11	25	—	10	12	30	—	90
H/H	0	30	30	18	28	23	28	24	28	24	29	0
												0

above phenomenon was considered. A detailed examination of typical "yellow-edge" plants used in the experiment and of runners derived from and grafted to these plants was made by Massee who reported that he was unable to find this nema present in any single instance. Further, if, as concluded by the American workers, the eelworm is ectoparasitic, the transmission of the disease by eelworm (directly or indirectly) would probably be prevented by the mite grease-traps. Finally the systemic nature of the "yellow-edge" disease shown by the transmission experiments and in field observations (see p. 70) would suggest that its cause travels *within* the plant tissue.

The evidence therefore favours the conclusion that the "yellow-edge" disease as defined in this paper is caused by a virus which can be transmitted to healthy plants by the process of grafting.

IV. SUMMARY OF SYMPTOMS ON "ROYAL SOVEREIGN."

By means of the above grafting experiments it has been possible to distinguish the symptoms induced by the virus from those due to other causes such as direct mite injury. These symptoms will now be summarized.

A. THE CRITICAL PERIOD FOR DIAGNOSIS.

One of the most marked features of the disease is that the characteristic leaf symptoms are only completely manifested during a limited period at the latter end of the growing season. In the above experiments leaf symptoms on grafted (A and B) runners were first recognized with certainty on August 10th in 1931, and August 26th in 1932. But it was not until October that the symptoms could be distinctly seen throughout the complete series. Thus in 1932 it was not possible to make a final survey of the graft units for "yellow-edge" until October 13th. That a corresponding delay in the appearance of leaf-symptoms was also observed on the type collection of "yellow-edge" plants used throughout the experiments has already been noted (p. 59). The same phenomenon was observed each year in field plantations. During the two years in which the disease has been under close observation, the diagnostic leaf symptoms have only been completely manifested *from the middle of September until the end of October*. Symptoms have been observed on individual plants before and after this "critical period" but hitherto it has been impossible to decide even tentatively, that a given plant is free from "yellow-edge" infection until this period has been reached. Up to the present no critical experiments to determine the cause of this natural masking of symptoms throughout the greater part of the growing season have been carried out, but general observations suggest that the phenomenon is related to the seasonal cycle of temperature. In this connection it should be noted that Plakidas (15) has shown by experiment that the symptoms of Xanthosis are masked by high temperatures (80° F. and over).

B. LEAF SYMPTOMS. (Plate IV, Fig. 1.)

The leaflets exhibit a chlorosis or yellowing confined to the marginal regions, invariably accompanied by (a) a general dwarfness, (b) an irregular curling (usually in an upward direction) of the marginal region, (c) a downward curling of the midrib, and (d) a twisting of the whole lamina. A complete leaf has a distorted and asymmetrical appearance due to the constituent leaflets showing the above symptoms in varying degrees.

The petiole is abnormally short, stout and lacking in red pigmentation. The intensity of the above symptoms varies with the stage of attack which has been reached. (See D. below.)

C. DISTINCTION OF LEAF SYMPTOMS FROM THOSE OF DIRECT MITE ATTACK.

The chlorosis or yellowing of young leaves caused directly by mite attack is, unlike that due to "yellow-edge," distributed over the whole leaf. It is, further, associated with a silvery brown speckly discolouration of varying intensity which is not present on plants infected with "yellow-edge" alone.

D. THE GENERAL APPEARANCE OF "YELLOW-EDGE" PLANTS.

(Plate IV, Fig. 2.)

Owing to the masking of "yellow-edge" symptoms by mite and insect infestation it is rarely possible to make a final diagnosis on the strength of symptoms shown by one or two individual leaves alone, the whole appearance of the plant must be considered.

During the "critical period" (September to October) the general appearance of a "yellow-edge" infected plant is very characteristic. This is due to the fact that the marginal chlorosis ("yellow-edge"), lack of red pigmentation, and general dwarfness and distortion is limited to the youngest leaves. The result of this is an abnormally "flat" plant consisting of a zone of more or less normal outer leaves enclosing a central zone of dwarf "yellow-edge" leaves. The degree of contrast between the outer and central zones of leaves varies according to the stage of intensity which the disease has reached. In cases of recent infection the central leaves and petioles are only slightly dwarfed and distorted and only partially deficient in red pigmentation. In advanced cases the central zone consists of a "tight rosette" of extremely dwarfed, distorted and chlorotic leaves entirely lacking in red pigmentation.

E. PREMATURE AUTUMNAL DISCOLOURATION.

It has been observed on artificially infected plants in the greenhouse, and also on naturally infected plants in the field, that the red autumnal colouration of the outer zone of leaves develops earlier on "yellow-edge" than on healthy plants.

F. THE SYSTEMIC NATURE OF THE DISEASE.

That the virus causing "yellow-edge" when introduced into a plant rapidly permeates the entire plant system is shown by the results of the above grafting experiments.

That under natural conditions the virus can pass from an infected plant into all the runner progeny of that plant during the course of a single season, was clear from the following field observations which were made in 1932 in connection with a field experiment at the Research Station designed to compare the entire progeny of certain selected *Royal Sovereign* plants. In October, 1931,

certain runners were selected from two specially chosen "healthy" parent-plants and were themselves laid down for runner production, being planted sufficiently widely to facilitate the separation of the entire progeny of each plant from that of its neighbour. In September, 1932, certain of these parent-plants exhibited clear symptoms of "yellow-edge" and it was observed that every runner derived from such plants also showed distinct symptoms of the disease. The contrast in vigour and appearance between such families and neighbouring healthy families was very marked.

V. THE INCIDENCE OF "YELLOW-EDGE" ON OTHER VARIETIES.

Although the main experiments described above were limited to the disease on *Royal Sovereign*, observations and preliminary experiments have been carried out with other varieties showing analogous symptoms, and in particular with *Stirling Castle* and *Stirlingworth*. On examining the Research Station plantations of *Stirling Castle* in September, 1931, it was found that all the plants and runners exhibited leaf symptoms very similar to those of *Royal Sovereign* "yellow-edge." The symptoms on the oldest planting were more advanced in intensity than those on the younger plantings although the latter were made with runners taken from the former, but in no case was it possible to pronounce any plant free from the disease.

A collection of *Stirling Castle* runners was potted up at this time and kept under close observation in a cool greenhouse during the 1932 season. As in the case of *Royal Sovereign* the leaf symptoms were completely inhibited on the great majority of these plants until early September, when the latest produced leaves showed distinct yellow-edges and pronounced dwarfing. By early October symptoms of varying intensity were distinctly visible on all the plants. The marginal chlorosis shown by this variety is much more vivid than on *Royal Sovereign*, probably due to the greater masking action of Mite on the latter variety. The leaf curling and distortion on *Royal Sovereign*, however, is much more pronounced than that on *Stirling Castle*. During 1932 only one runner suitable for grafting was produced by this collection of plants and this was grafted to a healthy *Royal Sovereign* plant. The graft was successful and, ultimately, typical *Royal Sovereign* "yellow-edge" symptoms developed on the A runner (*Royal Sovereign*) and on the "healthy" parent-plant (*Royal Sovereign*). It is probable therefore (on the evidence of this single graft) that the diseases on *Stirling Castle* and on *Royal Sovereign* are identical.

A collection of diseased *Stirlingworth* plants was made from a plantation near Swanley early in August, 1931. Although at this time it was a matter of difficulty to identify "yellow-edge" *Royal Sovereign* plants, a large proportion of the *Stirlingworth* plants and runners were showing analogous symptoms much

more vividly than those observable at any time (even in October) on Royal Sovereign. During 1932, unlike the comparable Royal Sovereign and Stirling Castle plants, "yellow-edge" symptoms were distinctly visible on all the Stirlingworth plants throughout the entire growing season, reaching a maximum distinctness, however, in October. Unfortunately no runners were thrown by any of these plants and therefore no grafting tests could be carried out.

Analogous "yellow-edge" symptoms have also been observed in the field on the following varieties: *Laxton*, *Deutch Evern*, *Jacunda*, *Madam Kooi*, *Flandern*, *Bedford Champion*, *King George V*, *Sir Joseph Paxton* and *Oberschlesien*.

It is clear from observation that varieties differ in susceptibility to "yellow-edge," but at this early stage sufficient data are not available to compare them in this respect. A preliminary survey of the Royal Sovereign strain-trial-plots at the Research Station carried out in October, 1932, also suggested that strains of a single variety may differ in susceptibility to "yellow-edge." Further records will be made to test this point.

VI. THE NAME OF THE DISEASE.

A comparison of the symptoms of the disease described in the present paper and those of strawberry Xanthosis as described by Plakidas in America (14, 15) indicates their very close similarity. As the vector of the American disease (*Myzus fragaefolii*) has not been recorded in this country, and as there are points of difference in the symptoms and seasonal cycle of the two diseases their identity cannot finally be established until facilities for a more detailed comparison are available.

The change of name of the American disease from "Yellows" to "Xanthosis" was suggested by Plakidas (15) because the former name was not used specifically of virus diseases but sometimes (as for example in the case of "Cabbage Yellows") referred to fungus diseases. In a later publication (17) this objection would appear to have been over-ruled for it is suggested that a new disease of strawberries occurring in the Northern and Eastern States of Canada (the outstanding symptom of which is a yellowing of the leaves) and thought to be caused by a virus, should be distinguished from the "Xanthosis" of California by calling it "Yellows."

Following the opinion expressed in a recent communication from the Committee for Plant Pathology of the British Mycological Society (25), there appears to be no necessity why the common name of a serious disease of a commercial crop should refer exclusively to a specific pathogen or class of pathogen. It is more important that the name should, by suggesting a salient diagnostic symptom, enable the grower to distinguish the disease from other diseases of the same plant. In order, therefore, to distinguish the present disease (i) from the diseases in

PLATE I.



FIG. 1. The manipulation of a "Graft-unit" in the 1932 experiment.



FIG. 2. 1931 *Experiment*. A grafted "healthy" runner from an H/Y graft showing transmission of "yellow-edge" symptoms.

Graft made on 19.5.31. Photo. on 7.8.31.

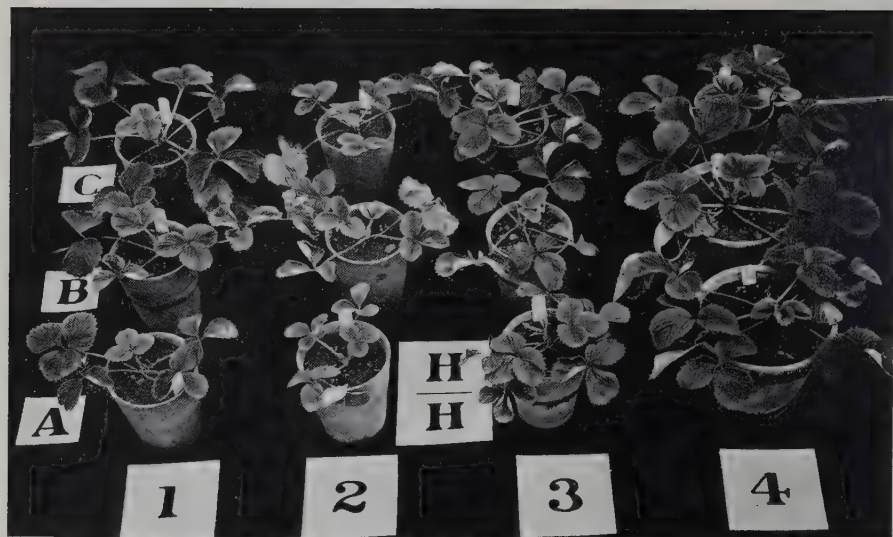


FIG. 1.

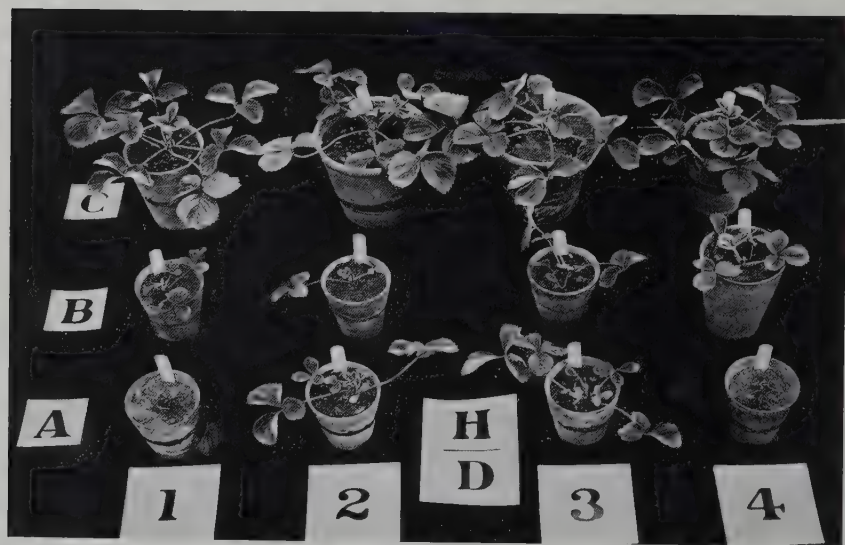


FIG. 2.

1932 Experiment. Comparative views of four typical graft-units (A, B and C runners) from the H/H series (Fig. 1) and the H/Y series (Fig. 2) respectively. Both sets photographed on 17.10.32 to the same scale.

Note normality of all runners in Fig. 1 and in Fig. 2 compare the degeneration and "yellow-edge" symptoms shown by the A and B runners with the normality of the C runners.

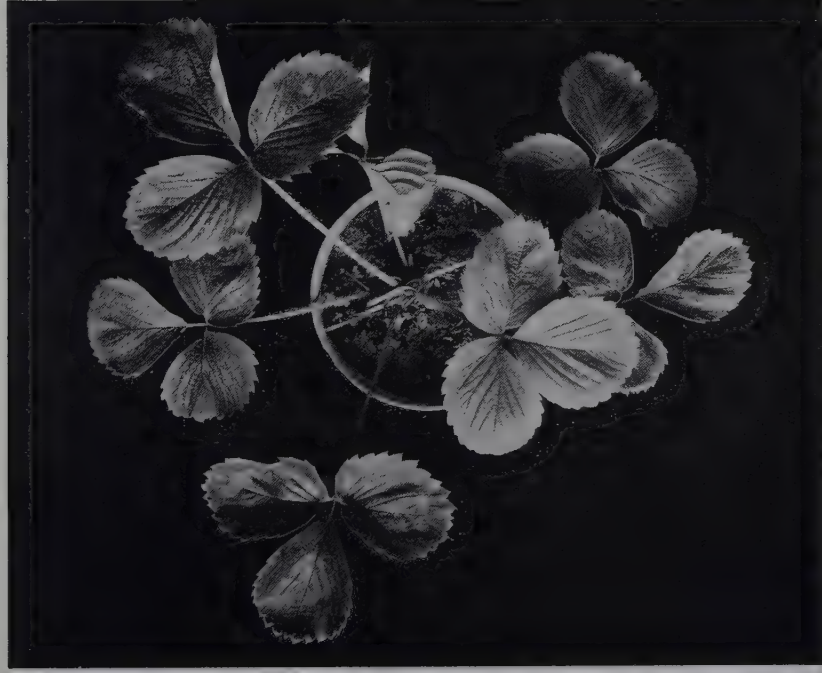


FIG. 1 ($\times 0.4$).

1932 Experiment.

The "C" runner (Fig. 1) and the "A" runner (Fig. 2) from a single-graft-unit in the H/Y series. Photographed on 16.9.32.

The "A" runner (Fig. 2) died in early October. Note "yellow-edge" symptoms on youngest leaf.

FIG. 2 (Nat. size).



PLATE IV.



FIG. 1. Four typical "yellow-edge" leaves and two comparable healthy leaves of *Royal Sovereign* selected from neighbouring plants in the same plantation on 12.10.32 (x 0.6).



FIG. 2. A general view of a typical "yellow-edge" infected *Royal Sovereign* plant. Photographed on 7.8.31.

America referred to as "Yellows," and (ii) from mite-plants, which often show a yellow colouration of the young leaves (not localized at the leaf-edge), it is proposed to refer to it as the *Strawberry* "Yellow-edge" disease.

VII. DISCUSSION ON CONTROL.

In the present early stages of the investigation any scheme of control which may be formulated must be regarded as purely tentative pending experimental verification.

It is clear that the unchecked spread of the virus in a susceptible variety such as *Royal Sovereign* will automatically result in a progressive reduction of the potentiality of the ordinary commercial stocks of runners. It is suggested that the complete degeneration and falling out of general commercial use of certain varieties (e.g. *Stirling Castle*) may well be the result of the ultimate permeation of the available stocks of such varieties by the virus of "yellow-edge" or of an analogous disease. A system of control must aim therefore at the elimination of virus-infected runners from the runner beds so that the grower can be confident at any stage in the career of a susceptible variety that the proportion of virus-infected runners in his supply will be negligible. This may be achieved by the control of the natural vectors of the virus and by the systematic elimination ("roguing") of infected plants from runner beds.*

Experiments for determining the vectors are in progress with special reference to the possible function in this respect of the *Tarsonemid* mite which has been identified on "yellow-edge" infected plants with remarkable constancy.

The success of attempted control by roguing runner beds will largely depend (i) on obtaining a virus-free nucleus of runners with which to build up the runner bed and (ii) on the degree of accuracy with which all subsequently infected plants are identified and eliminated. The latter can only be achieved by reducing as far as possible the masking of symptoms due to mite and insect infestation, and by carrying out final inspections during the "critical period of symptom manifestation," i.e. the latter half of September and October in the case of *Royal Sovereign* and *Stirling Castle*.†

In conclusion the writer wishes to express his special indebtedness to Mr. A. M. Massee for his untiring help in conducting the mite and insect control operations, to Mr. A. Tidy for his skilful care and manipulation of the plants throughout the experiments, to Dr. H. Wormald and Dr. R. C. Knight for valuable criticism in the writing of the present paper, and to Miss J. R. Hamond for transcribing the text-figures.

* Such a system is already in successful operation with similar diseases of other crops, e.g. black currants (Reversion) (1); and raspberries (Mosaic-disease) (11).

† Once a virus-free race of plants has been built up, the necessity of such late inspections should not preclude the taking of runners from the beds for early autumn planting.

SUMMARY.

1. An account is given of experiments in transmission by grafting carried out in 1931 and 1932 which demonstrate conclusively the existence in this country of a transmissible virus-disease of the strawberry which, independently of mite and insect infestation and of other external causal factors, induces a degeneration of infected plants and runners culminating in their sterility and death.

2. The diagnostic symptoms on *Royal Sovereign* and other varieties in the 1931 and 1932 seasons were only completely manifested on all infected plants from the latter half of September to the end of October. This periodic masking of symptoms is unrelated to that caused by insect infestation and its causes are discussed.

3. The principal symptoms on *Royal Sovereign* are a general dwarfing of the youngest leaves produced during the above "critical period," accompanied by a chlorosis, localized to the marginal region, and a curling and distortion of the constituent leaflets. The petioles of such leaves are short, abnormally stout, and lacking in the normal red pigmentation.

4. The general appearance of plants developing the above symptoms is very characteristic and is described, and the necessity for taking this appearance into account in diagnosis is pointed out.

5. Premature autumnal discolouration is induced on infected plants.

6. Preliminary observations on other varieties exhibiting analogous symptoms, and on relative varietal and "strain" susceptibility to the disease are summarized.

7. The close resemblance of the symptoms of the disease to those of the American *Xanthosis* as described by Plakidas, is pointed out. It is proposed at present, for reasons stated, to distinguish the present disease by the descriptive name of *Strawberry "Yellow-edge."*

8. The general lines along which the investigation of control measures should proceed are discussed in the light of the above results.

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A NOTE ON THE CONTROL OF THE RASPBERRY BEETLE (*BYTURUS TOMENTOSUS* FABR.) BY MEANS OF A BARIUM SILICOFLUORIDE WASH

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INTRODUCTION.

EXPERIMENTS on the control of the Raspberry Beetle larvae have shown that the degree of success obtained depends on the correct timing of the applications of a suitable insecticide. The eggs are laid on the recently set berries and on account of the raspberry flowers opening over a short or long period according to the season, it is impossible, particularly when the oviposition period is prolonged, to select the exact date or dates of the hatch of the majority of the eggs.

Recent experiments (1, 6) indicate that the suitable dates of application of a derris wash are within periods calculated to kill both the larvae that have just hatched from eggs, and also those that hatch, from eggs previously deposited, within a few days after the application of the wash. The success of a derris soap wash (0.004 per cent rotenone) depends on the length of duration of effective toxicity after application on the berries and shoots.

Earlier experiments had already demonstrated the efficacy of lead arsenate as a control. Three successive applications of a lead arsenate wash when approximately one-third, two-thirds and all the flowers are open provide a high control of the beetle; there is little doubt that in this case the majority of the larvae are killed by the last application. The unchanging toxicity of the arsenate accounts for the high control obtained and the degree of control is dependent on the adhesion of and number of berries covered by the wash before the larvae enter the berry. Since the original experiments with lead arsenate by Lees at Long Ashton the amount of the residue on the berries has been considered to be present in dangerous quantities. In one experiment Arnaud and Steer (5) showed that the residue was present in excess of the legal allowance (0.01 grain per lb. of fruit).

It was on account of the presence of this excess of poisonous residue that experiments were made subsequently at the Long Ashton and East Malling Research Stations with various non-poisonous preparations; of these, derris and pyrethrum have given the best results. Pyrethrum washes cannot at the present time be manufactured economically at a sufficiently high toxicity to give

equivalent results to derris. The toxicity of both derris and pyrethrum preparations depends, however, on the presence of organic compounds which cannot be so easily stabilized or standardized as inorganic compounds.

It was with this disadvantage in mind that a number of inorganic compounds were investigated still more recently at Long Ashton as a means of providing a control of the larvae. Barium silicofluoride provided the necessary properties in that the chronic toxicity to warm blooded animals is stated (7) to be approximately one-twelfth that of lead arsenate and therefore the health hazard is probably reduced to a negligible risk. Its toxicity is stable and thus the main point required is the adhesion of the material to the berries for a sufficient length of time.

In U.S.A. during the past few years fluorine compounds have been used experimentally as substitutes for arsenical washes. Newcomer (3) found that barium silicofluoride provided a control of the Codling Moth larvae equal to that obtained with lead arsenate. Other workers (2, 4) obtained equally satisfactory results with the control of other insects, and there seems no doubt that barium silicofluoride is an efficient stomach poison for a number of species of insects.

THE BARIUM SILICOFLUORIDE WASH.

The form of the barium silicofluoride used in the present trials was a preparation submitted for test by a chemical firm. The silicofluoride was in an extremely fine state of division and the particles were held in suspension by means of a protective colloid. It is essential that the compound should be in a fine state of division in order to prevent a very rapid settling out of the particles. The silicofluoride was used at a concentration of 12 lbs. per 100 gallons of water, to which 10 lbs. of soft soap had been added in order to aid the even distribution of the wash on the berries.

THE LAYOUT OF THE EXPERIMENT.

The following experiment was carried out in order to determine the results obtained with the barium silicofluoride wash and to compare them with those obtained with a pyrethrum emulsion.

The pyrethrum emulsion was used at a concentration that represented 1 per cent of the flowers. Seven units, each consisting of twenty-one stools of the raspberry variety Baumforth "A," were selected on account of the uniformity of the infestation by the beetles. Two units were sprayed with the silicofluoride, two units with the pyrethrum emulsion and three units were left unsprayed to act as controls. The flowering and egg-laying periods at Long Ashton in 1932 were short: approximately one-third of the flowers were open on June 10th and all the flowers open on June 14th. The majority of the beetles disappeared on June 16th and a large number of eggs were laid between the 10th-16th, i.e. over

a period of seven days. On account of the short egg-laying period it was considered necessary to make only one application of the washes. The incubative period of the egg is ten to twelve days and the washes were applied on June 22nd ; at this date the majority of the eggs laid on the first third of the flowers had hatched or were about to hatch. No rain fell during the period June 21st to July 15th. At the first pick it was impossible to obtain more than a few entire berries on account of the extensive damage caused by the adult beetles. The second pick was made on July 18th and random samples of 500 berries from each set of differently treated units were examined. The examination of the units sprayed with the pyrethrum emulsion was not continued after the third picking. The results of the examination of all the pickings are recorded in the following table.

Raspberries. Percentage Infestation.

Date of Examination.	Treatment.		
	Control.	Pyrethrum 1.0%	BaSiF ₆ .
18.7.32	35.2	25.8	4.4
20.7.32	36.8	23.8	3.8
22.7.32	34.2	23.6	4.6
25.7.32	29.8	—	3.0
27.7.32	29.2	—	4.6
29.7.32	19.1	—	6.4
3.8.32	20.4	—	6.4
Average	29.2	24.4	4.7

It is evident that one application of the barium silicofluoride provided a satisfactory control and the duration of toxicity was sufficient to ensure the death of the larvae hatching two to six days after application. The duration of effective toxicity of the pyrethrum emulsion must have been considerably less. There was no doubt that the pyrethrum emulsion killed all larvae it came into contact with at the time of application, on account of the thorough manner in which the berries were wetted and the high toxicity of the wash as a contact insecticide.*

The silicofluoride did not impart any bloom to the berries or foliage, but a number of the leaves on the fruiting canes were scorched. The reason for this damage has yet to be ascertained. The results are sufficiently encouraging to continue further experiments to determine the range of effective dilution of the wash and to secure data on the residue left on the mature berries.

* An indication of the relative efficiency of the pyrethrum and derris may be afforded by the following. A plot of the variety Lloyd George was adjacent to the Baumforth "A" raspberries. One portion was sprayed twice with the 1.0% pyrethrum emulsion and another portion with a derris soap wash at periods calculated to kill the larvae. The pyrethrum plot had 22.6%, and the derris plot 5.5% of the berries infested.

ACKNOWLEDGMENTS.

The writers are indebted to Miss K. Beard and Miss M. Carleton for their ready assistance in the examination of the berries, and to the Electro-Chemical Processes Ltd. for supplies of barium silicofluoride.

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OBSERVATIONS ON SPORE GERMINATION AND SPECIALIZATION OF PARASITISM IN *CYSTOPUS CANDIDUS*

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I. INTRODUCTION.

At the outset of these researches, the main problem was to work out the extent of physiological specialization in *Cystopus candidus*. Earlier workers had proved the existence of biologic forms of this fungus, and fresh material for cross-inoculation experiments was available in various parts of England on many Cruciferous hosts.

With a view to securing a suitable inoculum for cross-inoculations preliminary investigations on the germination of conidia were carried out. During these investigations considerable difficulty was encountered. Conidia were taken from freshly cut leaves of a particular host and sown in water at a suitable temperature for germination. In some experiments 98 per cent germination was secured. In others, in which many thousands of conidia were used, not a single conidium germinated. This indicated that some factor or factors other than water and temperature conditions could control the germination of the spores. Experiments showed that within wide limits the age of the conidia was not a controlling factor. It was noticed, however, that conidia from leaves gathered in wet weather invariably failed to germinate. The conidia of which the highest percentage germinated came from material gathered after several hours' sunshine. This suggested that one factor for germination might be linked up with the weather conditions prevailing before the conidia were gathered and sown in water. It was upon this possibility that the writer concentrated.

While germination experiments were being carried out, material was available for observing the exact mode of germination of the conidia, about which some controversy had existed. Having found that conidia germinated invariably by the production of zoospores, an investigation was made of the mode of infection by zoospores in various Cruciferous hosts.

II. REVIEW OF EARLIER WORK.

In 1911, Melhus⁷ reviewed the earlier work on spore germination, infection, and specialization of parasitism in *Cystopus candidus*. Accordingly, only a brief résumé of this will be given here.

The mode of germination of the conidia of *Cystopus candidus* was studied by Prévost⁸, Tulasne⁹, Hoffmann⁵, and de Bary². Prévost and de Bary found that germination occurred by the production of zoospores, but their observations on the exact mode of germination were incomplete. Tulasne and Hoffmann stated that the conidia germinated only by the production of germ tubes. Eberhardt³ confirmed de Bary's observations; he had much difficulty in securing germination, and attempted to demonstrate that the age of the conidia determined whether or not germination occurred, but his data were incomplete and his results unconvincing. In addition, Eberhardt carried out a number of cross-inoculations, using conidia from four different genera and inoculating other Cruciferous hosts. His results will be summarized later. They suggested the existence of biologic specialization in *C. candidus*.

Melhus⁷ also failed to observe the germination of conidia by the production of a germ tube. He studied the conditions affecting germination and showed clearly that zoospores were produced only at low temperatures. He showed that germination was not affected by light or darkness. Some of his results suggested that the time required from sowing the conidia to the production of zoospores varied according to seasonal changes. Infection experiments on the relative susceptibility of different host plants suggested that the most vigorous plants of any one species were the most susceptible, but that varietal resistance did not occur. Various Cruciferous hosts were inoculated with spores from *Raphanus sativus*. Infection was secured only on *R. sativus*, *R. caudatus* and *Brassica alba*. These experiments confirmed Eberhardt's suggestion that biologic specialization occurred in *Cystopus candidus*.

Hiura⁴, working in Japan, found three biologic forms of *Cystopus candidus*, one which infected *Raphanus sp.*, a second which infected *Brassica campestris* subspp., *B. rapa*, *B. pekinensis* and *B. juncea*, and a third which infected *B. cemua*, *B. juncea* and *B. campestris* subspp.

III. EXPERIMENTAL STUDIES.

(a) *Conditions affecting the germination of conidia.*

The conidia were generally obtained from naturally infected plants growing out-of-doors. Leaves bearing pustules were gathered and placed in air-tight tins until the spores were sown in water.

TEMPERATURE.

Melhus⁷ has shown the effect of low temperatures on the germination of conidia of certain species of *Cystopus*. In his experiments germination never occurred above 25° C. On the other hand conidia germinated best at strikingly

low temperatures. De Bary's experiments also showed this. In the present investigations germination occurred only at temperatures below 20° C.

Melhus suggested that the optimum temperature for the germination of conidia was 10° C., but he has published little evidence to support this. The writer has carried out a large number of experiments at temperatures ranging from 1° C. to 18° C. The results of these show that germination takes place equally readily at any of these temperatures, provided that other factors are favourable to the germination of the conidia.

Experiments were carried out also to determine whether or not it was more favourable to germination if the conidia sown in water were kept at high temperatures (20°-22° C.) for varying lengths of time, transferred to low temperatures (1°-18° C.) for varying periods, and then returned to high temperatures. Melhus placed spores at a low temperature for thirty minutes, then transferred them to a high temperature, but no germination occurred. He pointed out that this indicated that a change from high to low temperatures, and then back to high temperatures, did not lead to germination.

It was found in these investigations that conidia will often germinate if after immersion in water they are kept at high temperatures (20°-22° C.) for as long as one hour before cooling at 1°-18° C. Germination never occurred in controls kept at 20°-22° C. throughout. Occasionally germination took place after immersion in water at high temperatures for three hours, with subsequent cooling.

In most of the writer's germination experiments conidia were left at low temperatures until germination occurred. When the conidia were transferred to a high temperature after a short period of cooling, germination did not occur, but when the cooling period was sufficiently long, the spores germinated after being transferred to high temperatures.

WEATHER CONDITIONS DURING THE MATURATION OF THE CONIDIA.

As stated above, in all the earlier experiments carried out in these investigations there seemed to be a close correlation between the weather conditions prevailing before the conidia were gathered and the subsequent germination results.

Later experiments suggest that this correlation exists because of the influence of weather conditions on the water-content of the conidia. A change in the temperature or the relative humidity of the atmosphere causes a change in the rate of transpiration, and the water-content of the host tissues is affected. In a normal unopened pustule (this type was used throughout) the conidia are in intimate contact with the hyphae in the host tissues and with the host cells themselves. The walls of the conidia are readily permeable to water, as are the

cells of the host tissues. This permeability of the walls of the conidia can be demonstrated easily by taking the dried conidia, with their walls in a collapsed condition exactly like that of a punctured india-rubber ball. On immersion in water, the conidia absorb water with such rapidity that within about thirty seconds they appear to have absorbed the maximum amount of water and not a single indentation remains. It seems reasonable then to suppose that in any unopened pustule, an equilibrium is maintained between the water-content of the host tissues and that of the conidia. Hence any factors which affect the water-content of the host tissues will influence the water-content of the conidia.

The suggestion which seems to cover the facts most fully and which is substantiated by later experiments, is that before the conidia of *Cystopus candidus* will germinate, a lowering of their water-content must take place, as in many seeds of higher plants. This statement has been supported by every germination experiment carried out in these investigations, and there is no reason to doubt the fact that any influence which causes a moderate reduction in the water-content of the conidia increases the chances of successful germination. The onset of a spell of warm or dry weather, which causes an increase in the rate of transpiration, will result in a lowering of the water-content of the host tissues and therefore of the conidia ; this directly affects the germination capacity of the conidia.

In about one hundred germination experiments records were kept of the weather conditions existing before the conidia were gathered (considered for their effect on transpiration). Each experiment was carried out in the early afternoon. A record of the weather conditions was taken for the previous seven hours (i.e. beginning in the early morning, when the water-content of the host tissues and conidia was nearest its maximum) relative to the general weather conditions prevailing for several days before the experiment. These experiments showed that germination occurred only when the weather conditions during the seven hour period were warmer and drier than those existing on the preceding days. Even when these conditions were fulfilled, however, it was found frequently that germination did not occur. This indicated that if the lowering of the water-content of the conidia governed germination, the limits of loss in water-content within which germination occurred were very narrow.

Attempts were made to measure the amount of drying necessary for germination to take place. It might reasonably be assumed that this could be done by measuring the amount of drying of the host tissues. This method would not be accurate, because differences between the osmotic pressures of the conidia and host cells would result in differences between the rates of loss of water from the two types of cells. The method would be an approximate one, however, and it would have been extremely difficult to have attempted to measure directly the loss in water-content of the conidia.

Preliminary experiments were carried out with conidia from *Senebiera coronopus*, *Arabis alpina* and *Brassica oleracea*. Leaves bearing pustules were gathered after several hours' rain and placed in a warm, dry atmosphere. Conidia were taken at various intervals and sown in water under the optimum conditions for germination. Spores taken after fifteen minutes failed to germinate. Conidia from all three hosts germinated after from one to two hours' drying, the germination of *Arabis* and *Brassica* conidia lagging behind that of *Senebiera* conidia, the leaves of which wilted more rapidly. After five hours' desiccation, no germination occurred.

The main experiment will now be described in detail.

On August 24th, after a wet summer, 1.4 inches of rain fell in the district in which the experiment was being carried out. Early the next morning the rain ceased and a spell of sunshine began to dry the leaves of the host plants (*Senebiera coronopus*, *Arabis alpina* and *Capsella bursa-pastoris*). Immediately the last traces of rain had dried from their surfaces, the leaves bearing pustules were gathered and placed in air-tight tins. The leaves were packed closely but not tightly, and the tins were of such a size that when filled very little air space remained in them. In this way the water-content of the leaves was kept as nearly as possible constant until the beginning of the experiment. It was assumed that these leaves held approximately the maximum amount of water.

On August 26th the weather was fine and warm. There was practically no wind and very little cloud. Leaves of the three species were removed from the tins, weighed, and laid on sheets of corrugated paper spread out-of-doors in full sunlight. The initial weights were from 29 to 91 grams, and the leaves were laid in a single layer with their lower surfaces downwards. Temperatures and relative humidities were recorded at regular intervals during the course of the experiment. The leaves were collected and weighed on the spot every fifteen minutes for the first one and a half hours and at rather longer but regular intervals afterwards. After nine hours the leaves were air dried in the laboratory for a further twenty-four hours, and finally dried in an oven at 58° C. until the weights remained constant. In this way the dry weights of the leaves were obtained.

During the following day similar weather conditions prevailed, but a slight wind tended to lower the temperature and prevented the experiment being concluded out-of-doors. The remaining leaves bearing pustules were removed from the tins and spread out in a dry glasshouse; by careful attention to the ventilators the atmospheric conditions inside the house were made to correspond very closely with those out-of-doors on the previous day. At intervals corresponding to those in the first half of the experiment, spores were taken from

the drying leaves and sown in water at a suitable temperature for germination. The results of this experiment are represented graphically in Fig. 1.

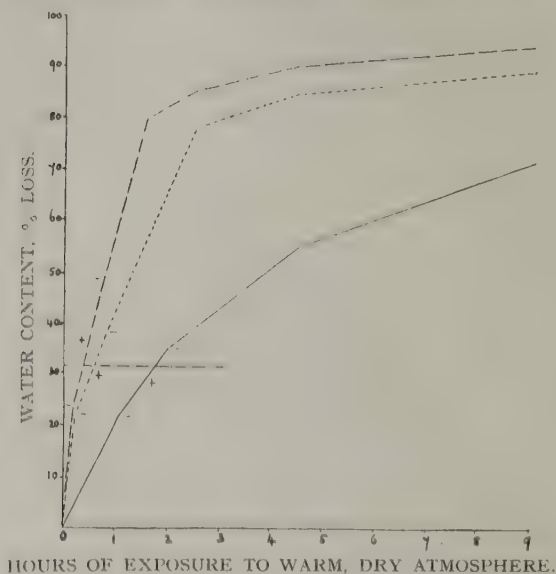


FIG. 1.

Influence on germination of loss in water-content of the conidia.

- *Senebiera coronopus*.
- . - . *Capsella bursa-pastoris*.
- *Arabis alpina*.
- +
- Germination positive.
- Germination negative.
- Suggested level for optimum germination.

The irregularities of the transpiration curves are due to slight differences in the time intervals between consecutive weighings and to variations in the rapidity with which the leaves were weighed and returned to the drying sheets.

It will be seen from the graph that germination occurred in the conidia from the three host plants only when the loss in water-content before sowing was between 28 and 30 per cent. In no case was a very high percentage germination recorded. This probably was because the time intervals were too long. Had they been shorter, it is likely that somewhere near the positive marks on the curves the optimum degree of drying would have been found at which germination would have been nearer 100 per cent.

The results of this experiment do not give exactly the amount of drying necessary for spore germination. A possible level for this amount, suggested by the data obtained, is indicated in the graph, although this can be only approximate. The experiment suffices, however, to give some indication of this amount, and it shows clearly that a certain amount of drying is essential for the germination of the conidia.

Melhus⁷ observed that after sowing conidia in water, the time required for germination varied from one to thirty-six hours, and that this variation was linked up with seasonal changes. He found that the shortest periods of cooling sufficient to bring about germination occurred in August, when the average length of the cooling period was $3\frac{1}{2}$ hours. In September the average was about $7\frac{1}{2}$ hours, and in October 9 hours. The longest periods were recorded in October. These results indicated that the requisite period of cooling was longer in the autumn than in the summer. This fact had been pointed out previously by Zalewski¹⁰.

Table I is a summary of the writer's experiments in which observations were made on the duration of the period between the sowing of the conidia and the production of the first zoospores.

TABLE I.

Duration of period between sowing the conidia and the production of zoospores.

Month.	Duration of Period.			No. of Experiments.
	Min.	Max.	Average.	
February	$1\frac{3}{4}$ hours	143 hours	81 hours	7
May	$1\frac{1}{2}$ hours	4 hours	$2\frac{1}{2}$ hours	14
June	$1\frac{1}{2}$ hours	3 hours	$2\frac{1}{2}$ hours	15
July	2 hours	$2\frac{1}{2}$ hours	$2\frac{1}{2}$ hours	5
August	1 hour	6 hours	$3\frac{1}{2}$ hours	11
September	1 hour	$1\frac{1}{2}$ hours	$1\frac{1}{2}$ hours	4
October	2 hours	$3\frac{1}{2}$ hours	3 hours	7

These results also indicate that the duration of the period between the sowing and the germination of the conidia is longer during the winter than during the summer months. The figures are not so regular as those obtained by Melhus. This may be accounted for by the small number of experiments, and by weather conditions in England often varying as much from day to day as from season to season.

In each of the writer's experiments in which records were kept of both weather conditions and the duration of the period between the sowing of the conidia and the production of zoospores, a correlation existed between the rate of loss of water-content of the conidia and the duration of this period. The more rapid the loss, the shorter was the period before germination and *vice*

versa. This holds good in both daily and seasonal variations. When weather conditions were such that transpiration in the host leaves was very rapid, the spores dried very quickly and germinated after an average period of about two hours. When transpiration was moderately rapid, the average period was $5\frac{1}{4}$ hours, and when transpiration was very slow, as in February, the period was much prolonged. This indicated that when the conidia dried very slowly they might function as "resting" spores.

Blackwell and Waterhouse¹, working on spore germination in *Phytophthora spp.*, stressed the importance of the particular state of maturation of the conidia in determining the type of germination. They pointed out that the keynote to the successful production of ripe resting spores is a long period on a slowly drying medium.

AGE OF CONIDIA.

The age of the conidia has been considered as another determining factor in germination. Eberhardt³ suggested that this was the most important factor, but his observations are of little value because his experimental data are incomplete. He collected leaves bearing unopened pustules and kept them wrapped in a damp cloth until the pustules were about to burst. He then

TABLE II.

Summary of experiments showing that within wide limits the age of the conidia is not a controlling factor for germination.

Source of conidia.	Condition of epidermis above pustule.	Age of pustule.	Condition of leaf.	Germination.
<i>B. alba</i> .. <i>B. rapa</i> ..	Unruptured	Very young (6 and 7 days after inoculation)	Fresh	—
		Young (8, 9 and 10 days after inoculation)	Fresh	+
		Old (10-14 days after inoculation)	Fresh	+
	Ruptured	Old (10-18 days after inoculation)	Fresh	+
<i>B. tenuifolia</i> .. <i>B. alba</i> .. <i>B. rapa</i> .. <i>Capsella b.p.</i> .. <i>Arabis alpina</i> ..	Unruptured	Young	Fresh	+
		Old	Fresh	+
	Ruptured	Old	Fresh	+
			Partially dried	+
			Very dry	—

sowed the conidia in water and found that germination took place. He made the assumption that germination results were positive when the conidia were seen to become swollen and "bottle-necked." This assumption is unjustifiable, however, for it has been found that when conidia remain papillate for a considerable length of time (i.e. longer than a few minutes) germination does not occur.

Melhus⁷ found in many of his experiments that conidia from pustules just about to open failed to germinate. Numerous germination experiments were carried out by the writer, using conidia from pustules of different ages. The results of these experiments are summarized in Table II.

(b) *Mode of germination of conidia.*

The conidia on gathering were sown in hanging drops of water, cooled, and then were usually kept at laboratory temperatures of 15-20° C.

Prévost⁸, de Bary⁹ and Melhus⁷ found that the conidia of *Cystopus spp.* germinated invariably by the production of zoospores. This has been confirmed by the present writer.

De Bary has described in detail the way in which the zoospores are formed and liberated from the conidium. The observations recorded in the present investigations agree in part with this description, but they are more complete. For this reason de Bary's description will be repeated, with additional observations made by the writer in italics:

When a conidium is sown in water, a certain amount of water is absorbed and the spore swells slightly. Vacuoles form in the granular protoplasm within the conidium, but these disappear later. Fine lines of demarcation, *not always visible before the liberation of the contents of the conidium*, divide the protoplasm into from five to eight or rather from four to sixteen polyhedral portions. A small vacuole is left at the centre, *but this likewise is not always visible*. On one side of the conidium an obtuse papilla develops. This opens *or more generally becomes extended to form a rounded vesicle, into which the zoospores are liberated in a more or less imperfectly differentiated mass*. Once outside the conidium, the zoospores become lenticular in form and remain in a spherical mass before the opening of the conidium. Soon cilia appear, and the globular mass is set oscillating. *A membrane appears to be formed round each zoospore before the latter becomes detached from the zoospore mass*. The zoospores soon become free from one another *and the vesicle increases in size, its maximum diameter being from two to four times the diameter of the conidium*. The zoospores swim round and round inside the vesicle. *Eventually the wall of the vesicle bursts* and the zoospores are able to swim away (Fig. 2).

Observations were made on the time required for each of the stages in the germination of conidia. It was found that the protoplasmic contents of the

conidium are ejected into the vesicle within about ten seconds. These remain stationary for from one to four minutes before oscillation begins. Only about one minute elapses from the time when the zoospore mass begins to oscillate to the bursting of the vesicle wall.

The frequency with which abnormalities occur during the process of zoospore formation has been studied. Very commonly the germination of the

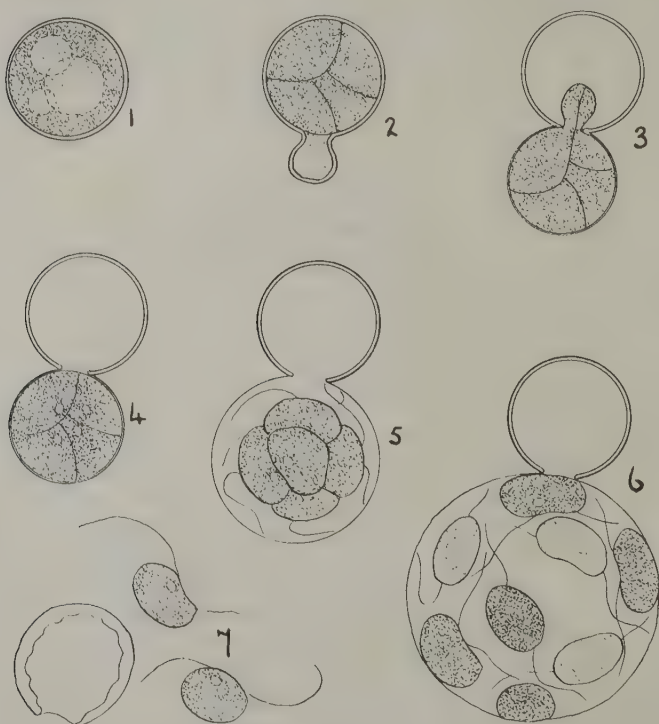


FIG. 2.

Stages in the germination of conidia, $\times 1,035$.

conidium never proceeds beyond the production of a papilla. Abnormalities occur much more frequently in the germination of conidia which have dried very slowly and which germinate only after immersion in water for a considerable time. In conidia which have dried rapidly it is common to find that 98 per cent germinate normally.

The zoospores remain motile for a varying length of time, which seems to depend largely upon the temperature of the water in which they are placed.

Zoospores kept at temperatures below 10° C. frequently remain motile for twenty-four hours. At temperatures above about 22° C. the zoospores invariably come to rest within a few minutes. After the period of motility, the zoospores either disintegrate or produce germ tubes. Abnormal zoospores have never been seen to produce germ tubes. In either case the zoospores nearly always come to rest against either a solid surface or the free surface of the water in which the conidium has germinated.

Tulasne⁹ and Hoffmann⁵ described the germination of conidia of *Cystopus candidus* by the production of germ tubes. This mode of germination has never been observed in the present investigations. It is possible that these earlier workers obtained spore suspensions of *C. candidus* contaminated with the conidia of *Peronospora parasitica*, which germinate fairly readily by the production of germ tubes. These two fungi occur together commonly, and the conidia of *P. parasitica* are similar in appearance to those of *C. candidus*. Or it is possible that these workers mistook for germ tubes the papillae which develop commonly in conidia in which the production of zoospores does not proceed normally. It is easily understood why these earlier workers failed to observe germination by the production of zoospores, for this mode of germination occurs only under certain limited conditions.

(c) *Mode of infection by zoospores.*

The penetration of the stomata by the germ tubes produced by the zoospores could be observed much more easily in cotyledons than in foliage leaves. Because of this, cotyledons were used almost exclusively in experiments on the mode of entry of the parasite.

Preliminary experiments showed that the germ tubes entered either epidermis equally readily, so films of water containing a thick suspension of motile zoospores were spread over the upper epidermis of the cotyledons, as this was more easily inoculated than the lower epidermis. The inoculated cotyledons were kept under a bell-jar for several hours to prevent evaporation of the inoculum, and were afterwards fixed at various intervals.

A number of fixatives were used in preliminary experiments, but as 70 per cent alcohol was found to be as satisfactory as any of the more elaborate fixing agents, this was used throughout later experiments. All the better known standard stains were tried, but none proved as good as lacto-phenol and cotton blue. The method of staining used has been described by the author (Hough⁶).

A suspension of zoospores was obtained from conidia taken from *Capsella bursa-pastoris*, and cotyledons from the same species were inoculated. Material was fixed 6, 18, 30 hours, and 3, 4, 5 and 6 days after inoculation. This was stained and examined in bulk and in microtome sections.

In every cotyledon examined in bulk and in countless sections, it was found that the germ tubes of numerous zoospores had penetrated the tissues of the cotyledons. In every case the mode of entry was by way of the stomata. This could be seen particularly clearly in material fixed six hours after inoculation, but even in material fixed six days afterwards, when the hyphae were abundant in the tissues of the cotyledon and when pustules were being formed

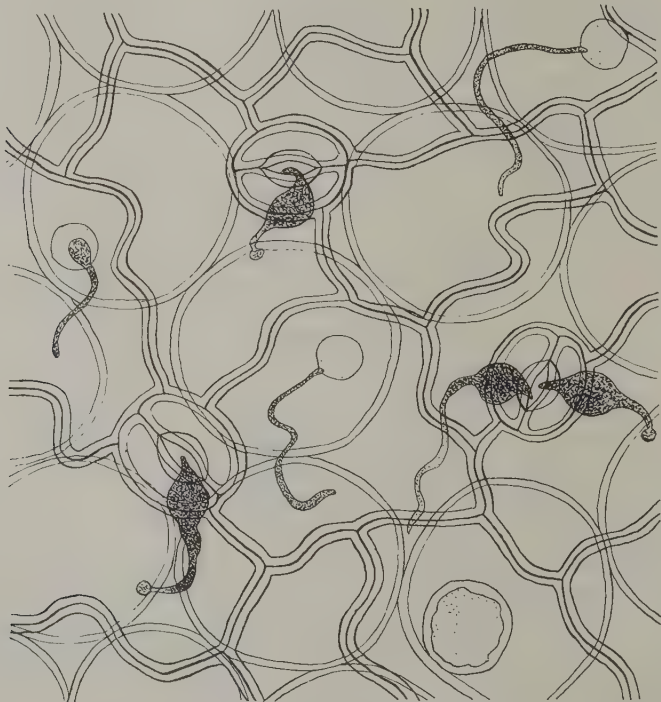


FIG. 3.

Surface view of cotyledon infected with *Cystopus candidus* (six hours after inoculation),
× 675.

above the lower epidermis, it was possible to pick out the oldest part of the mycelium still attached to the stoma through which the germ tube had entered.

It was found that on entering the sub-stomatal cavity of the host tissues, the germ tube became swollen and a sub-stomatal vesicle was formed as in many other fungi. Often within a few hours of inoculation the germ tube established its first haustorium in one of the host cells (Fig. 3).

In the same way the mode of entry was investigated in *Arabis alpina*, *Brassica alba* and *Iberis amara* cotyledons and in *B. alba* leaves. In every case infection took place by way of the stomata.

Capsella cotyledons were inoculated also with zoospores of other strains of *Cystopus candidus* which would not grow on *Capsella*. Conidia from *Arabis alpina* and *Brassica rapa* were used in these inoculations. *Arabis* cotyledons were inoculated with zoospores of *Capsella* and *Brassica oleracea* strains, neither of which will grow on *Arabis*. In each case it was found that the germ tubes entered the stomata of the wrong hosts, but that the growth of the germ tube did not proceed beyond the production of the first haustorium.

(d) *Specialization of parasitism.*

Before cross-inoculation experiments could be carried out, it was necessary to ascertain the optimum stage in the growth of the host plants for infection by *Cystopus candidus*. It was found that the growth of the fungus was very slow in old foliage leaves, more rapid in mature and young foliage leaves, and most rapid in young cotyledons. Young cotyledons were used for these cross-inoculation experiments also because seedlings could be grown more quickly and on a larger scale than older plants bearing foliage leaves.

In the earlier cross-inoculation experiments the seedlings were grown in pots under glass. Later, they were grown in pots out-of-doors and in the open ground. Good infection results were obtained in seedlings grown under each of these conditions, but the growth of the mycelium was most rapid and the pustules formed were largest in seedlings grown in plots out-of-doors. When a very thick spore suspension was used in the inoculation of susceptible seedlings grown under glass, the fungus produced a large number of small pustules. When seedlings grown out-of-doors were inoculated with a similar spore suspension, the whole surface of each cotyledon was commonly covered by one large pustule.

Much difficulty was encountered in securing an effective inoculum. The conidia taken from any host plant germinated only under limited conditions, and a very large number of conidia were required for each cross-inoculation experiment. As it was impracticable to obtain a sufficiency of conidia from plants grown specially for stock cultures, reliance had to be placed on supplies of conidia from plants infected naturally. It was impossible to determine the relative water-content of these conidia at the time of gathering. Hence it was largely a matter of chance whether or not zoospores could be obtained at the right time for cross-inoculation experiments.

No appreciable varietal resistance to *Cystopus candidus* was found in any of the species tested. Melhus⁷ tested thirty-nine varieties of *Raphanus sativus*, and the writer tested twelve varieties of *Brassica oleracea* f. *gemmifera*, three

varieties of *B. oleracea* f. *botrytis*, six varieties of *B. oleracea* f. *capitata*, and mixed varieties of *Alyssum*, *Iberis* and *Cheiranthus* spp. In no case was any marked degree of varietal resistance found.

The following host plants were used in cross-inoculation experiments carried out by the author:

<i>Alliaria officinale</i> .	<i>Brassica rutabaga</i> (swede).
<i>Alyssum maritima</i> .	<i>Brassica sinapis</i> (charlock).
<i>Arabis alpina</i> .	<i>Brassica tenuifolia</i> (rocket).
<i>Brassica alba</i> (mustard).	<i>Capsella bursa-pastoris</i> .
<i>Brassica napus</i> (rape).	<i>Cheiranthus cheiri</i> .
<i>Brassica oleracea</i> .	<i>Diplotaxis muralis</i> .
f. <i>capitata</i> (cabbage).	<i>Iberis amara</i> .
f. <i>bullata</i> (Savoy cabbage).	<i>Lepidium sativum</i> .
f. <i>gemmifera</i> (Brussels sprout).	<i>Nasturtium officinale</i> .
f. <i>botrytis</i> (broccoli).	<i>Raphanus sativus</i> .
f. <i>acephala</i> (kale).	<i>Sisymbrium officinale</i> .
f. <i>caulo-rapa</i> (kohl-rabi).	<i>Thlaspi arvense</i> .
<i>Brassica rapa</i> (turnip).	

The results of these experiments are given in Table III.

Before discussing the extent of physiologic specialization in *Cystopus candidus*, as suggested by the results of these experiments, the results of other workers will be given in a similarly tabulated form (Table IV).

Where positive infection was recorded in my experiments, and as far as is known in each experiment carried out by others, 14-100 per cent infection occurred in every case, except where stated otherwise. In about half of the positive infections recorded by the writer at least 75 per cent of the inoculated cotyledons became infected. Controls were kept in every experiment, but only in two experiments was infection recorded on control seedlings. In each of these, less than 6 per cent infection occurred on one species only, and it was extremely unlikely, therefore, that natural infection had affected the results recorded in these experiments. All results recorded as negative were completely so.

No infection was assumed unless pustules appeared on the cotyledons, as sections showed that in the absence of pustules within a reasonable period infection had not occurred.

These results confirmed the suggestion of previous workers that physiologic specialization certainly exists in *Cystopus candidus*. The results also indicate the existence of a large number of different biologic forms of the species. Eberhardt² indicated the possible existence of four different biologic forms.

TABLE III.
Specialization of parasitism in *C. candidus* (experiments carried out by author).

Date inoculated.	Source of conidia.	Average no. of colonies inoculated in each species.	Infection.																		
			<i>Alliaria</i> .	<i>Alyssum</i> .	<i>Arabis</i> .	<i>B. alba</i> .	<i>B. napus</i> .	<i>B. oleracea</i> .	<i>B. rapa</i> .	<i>B. rutabaga</i> .	<i>B. sinapis</i> .	<i>B. tenuifolia</i> .	<i>Capsella</i> .	<i>Cheiranthus</i> .	<i>Diphloxys</i> .	<i>Iberis</i> .	<i>Lepidium</i> .	<i>Nasturtium</i> .	<i>Raphanus</i> .	<i>Sisymbrium</i> .	<i>Thlaspi</i> .
22/ 7/29	<i>Arabis</i>	36																			
24/ 9/29	<i>Arabis</i>	50																			
27/ 6/31	<i>Arabis</i>	80																			
4/11/29	<i>B. alba</i>	50																			
9/ 6/30	<i>B. oleracea</i>	80																			
19/ 6/30	<i>B. oleracea</i>	80																			
29/ 7/30	<i>B. oleracea</i>	100																			
9/ 8/31	<i>B. oleracea</i>	120																			
8/ 5/30	<i>B. rapa</i>	50																			
30/ 6/31	<i>B. sinapis</i>	100																			
11/ 6/31	<i>B. tenuifolia</i>	100																			
25/ 6/31	<i>B. tenuifolia</i>	100																			
30/ 6/31	<i>B. tenuifolia</i>	100																			
29/ 5/29	<i>Capsella</i>	56																			
16/ 6/29	<i>Capsella</i>	20																			
29/10/29	<i>Capsella</i>	40																			
11/ 6/30	<i>Capsella</i>	80																			
29/ 7/30	<i>Capsella</i>	100																			
11/ 6/31	<i>Capsella</i>	86																			
12/ 6/31	<i>Capsella</i>	92																			
25/ 6/31	<i>Capsella</i>	100																			
30/ 6/31	<i>Capsella</i>	100																			
10/ 7/31	<i>Capsella</i>	100																			
7/ 8/31	<i>Capsella</i>	120																			
9/ 8/31	<i>Senecio</i>	36																			
14/ 8/31	<i>Senecio</i>	100																			
10/ 7/31	<i>Sisymbrium</i>	80																			

* = 5% infection.

Melhus⁷ worked with the form occurring on the radish. Hiura⁴ also found this form and proved the existence of two others. The writer's results show that twenty-one other biologic forms exist.

It appears also that numerous different biologic forms may grow on the same species of host. In these investigations twenty-one different forms were found which will infect *Brassica alba*, and Melhus found one other form infecting this host. Ten different forms were found by the writer to infect species of *Capsella*. Eberhardt found three others infecting *Capsella* species. The present experiments have shown the existence of at least thirteen different forms on *Iberis amara*, ten on *Lepidium sativum*, six on *Thlaspi arvense*, five on *Cheiranthus cheiri*, two on *Sisymbrium officinale*, and two on *Brassica oleracea*.

In the twenty cross-inoculation experiments carried out in the present investigations, in which the forms were taken from twenty-seven more or less widely separated parts of the country, twenty-one different biologic forms were found. This suggests that further experiments would probably reveal the existence of numerous other forms, for *Cystopus candidus* occurs in almost all temperate and many sub-tropical parts of the world.

The many completely negative infection results obtained in these cross-inoculation experiments indicated the fixity of biologic forms of *Cystopus candidus*. This was confirmed by field observations, for wherever different Cruciferous plants were growing side by side under natural conditions, it was common to find one type of host heavily infected with *C. candidus*, while not a trace of infection could be detected in the other genera.

The geographical distribution of particular forms was found often to be more local than general. For example, the biologic form on varieties of *Brassica oleracea* was commonly found in the extreme south-west of England, but comparatively rarely elsewhere. The form on *Brassica rapa* was found only in certain parts of Somerset, although extensive search was made for it in six other counties. Forms having the widest host range occur not only most commonly but most generally. Such forms are those on *Capsella* and *Arabis*, some of which have been found to infect host plants of six different genera. These forms occur in almost all parts of the country.

After it had been found that overlapping host plants occurred, the possible existence of "bridging" hosts was investigated, but the results of these investigations were entirely negative.

(e) *Influence of the water-content of the host on infection.*

Experiments showed that in a susceptible host both the cotyledons and the leaves (excluding moribund leaves) could be infected with *Cystopus candidus*, and that growth was most rapid in young and mature cotyledons, less rapid in young and mature leaves and least rapid in old cotyledons and leaves.

Melhus⁷ observed that plants attacked by aphides and thrips, or plants unhealthy in any way, seemed to be quite immune to *Cystopus candidus*, and that in healthy plants the extent of infection seemed to depend upon the vitality of the host, so that commonly the largest and most "succulent" plants were found to be the most susceptible. In earlier experiments the writer obtained some evidence in support of Melhus' observations, and the fact that fungal growth was poor in old leaf tissues seemed to be associated therewith. It was noticed, also, that in plants grown and infected out-of-doors, the pustules were produced after a shorter incubation period and were larger when the weather conditions were favourable to "succulent" growth of the host plant, i.e., when rainfall was heaviest, provided, of course, that the temperature was not too low and the soil was properly drained.

The possibility arose that immunity and feeble infection might be brought about by the water-content being too low for fungal growth in tissues which were old, lacking in vigour, or attacked by insects. Abundant moisture favours the growth of many fungi, so it was thought that the growth of *Cystopus candidus* might be controlled similarly by the water-content of the host tissues.

Preliminary experiments were carried out to ascertain whether or not susceptibility to *Cystopus candidus* could be reduced by lowering the water-content of the host plant. Ten days old seedlings and ten weeks old plants of both *Brassica alba* and *B. rapa* were grown in pots and inoculated with the appropriate biologic forms of *C. candidus*. The older plants were divided into two groups, (a) those which had been potted on when necessary and given an abundant supply of water, and (b) pot-bound plants which had been watered only every 48 hours. During the incubation period plants growing in group (a) were large and "succulent," while those growing in group (b) were stunted and dry in texture. The following percentage infection results were obtained:

10 days old.				10 weeks old.	
				(a)	(b)
<i>B. alba</i>	..	..	100	66	20
<i>B. rapa</i>	..	..	60	32	0

These experiments showed that susceptibility to infection was reduced by lowering the water-content of the host tissues. A further experiment was carried out with plants of *Capsella bursa-pastoris* in order to confirm the results of the preliminary experiments. Forty four-inch pots were filled with a rich potting compost and several seedlings were grown in each until they were a fortnight old. Then all but one, two or three plants were removed from each pot. Eighty-eight of these plants were allowed to grow on for ten weeks, during which time they were watered only once every 24 hours. The weather on the whole was hot and fairly dry, so the plants soon became stunted, owing to the

insufficient water supply. The plants were then inoculated with *Cystopus candidus* zoospores, and controls, ten days and ten weeks old, grown with an abundant supply of water, were inoculated similarly. Ninety per cent infection was secured on the controls, but on the stunted plants only two leaves became infected out of 520 inoculated.

IV. CONCLUSIONS.

The view concerning the loss of water during the maturation of the spores of certain fungi as being a factor essential to their germination does not appear to have been suggested by previous workers, but much evidence in support of this view has been found during these researches.

In addition, the writer has observed that the spores of many fungi break away from the conidiophores and separate from each other with particular readiness when their maximum water-content has been reduced. It is probable that maturation and dissemination of fungal spores are brought about by similar environmental conditions.

Work on the specialization of parasitism in *Cystopus candidus* confirms the fact that a large number of biologic forms of this fungus occurs, as in various members of the Erysiphales and the Rust and Smut Fungi. It is interesting that in *C. candidus* such widely different host plants as mustard, wallflower and watercress may be infected by the same biologic form of the fungus.

V. SUMMARY.

1. After cooling from a higher temperature the conidia of *Cystopus candidus* will germinate at temperatures between 1° C. and about 20° C., provided that other factors are favourable for germination.

2. Germination will not take place unless the maximum water-content of the conidia has been reduced by about 30 per cent. The water-content limits outside which germination is negative are narrow. The lowering of the water-content of the conidia depends upon the drying of the host tissues, and this depends upon weather conditions. Within limits, the more rapid the loss in water-content, the shorter is the period between the immersion of the conidia in water and their germination, and the higher the percentage of conidia germinating normally.

3. Within wide limits the age of the conidia is not a controlling factor for germination.

4. When germination takes place, the zoospores are ejected in a more or less imperfectly differentiated mass into a rounded vesicle in which their formation is completed. The period of motility of the zoospores decreases as the temperature increases.

5. Infection of susceptible plants takes place invariably by way of the stomata. The germ tube enters the tissues of resistant plants, but its growth does not proceed beyond the production of the first haustorium.

6. A large number of biologic forms of *Cystopus candidus* occur. Some forms can infect host plants of six different genera. It is common to find overlapping hosts, but no evidence has been obtained in support of the existence of "bridging" hosts.

7. No appreciable varietal resistance has been found.

8. Within a susceptible species mycelial growth increases with the water-content of the host tissues.

VI. ACKNOWLEDGMENTS.

The present investigations were undertaken at the suggestion of Mr. F. T. Brooks, to whom the writer is indebted for guidance and valued criticism throughout. Thanks are due also to Mr. A. Beaumont for assistance while part of the work was being done at the Seale-Hayne Agricultural College, Devon, to Professor Stiles for assistance on certain physiological problems, and to Mr. A. Sharples for suggestions during the preparation of the manuscript. Professor Lang kindly permitted the writer to use his laboratory during some of these researches.

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OBSERVATIONS ON PEAR SCAB

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THE observations included in this paper relate mainly to shoot infections and to the results of spraying trials in a commercial plantation. The work on shoot infections is similar to that previously carried out on the apple (Marsh and Walker, 1932), a description of the cycle of development of *Venturia pirina* on the shoots being followed by records of dissemination of spores from this source. The results of the spraying trials are included since the author has found no other published record of a large-scale spraying trial against pear scab in this country, and, for a similar reason, notes on spray damage have been added.

SHOOT INFECTIONS.

LITERATURE.

In the literature relating to pear scab on shoots, outstanding papers are those by Aderhold, Ducomet and Salmon.

Aderhold's description of scab attack on pear shoots was given in 1896. He noted the initial superficial growth of the fungus becoming sooner or later hemmed in by the epidermal cork and penetrating deeper to form a stroma which extended widely beneath the bark, finally splitting off the overlying tissue. The fungus fructification thus exposed was described as made up of a tuberculate cluster of stromata united only at their bases and thickly covered with conidiophores. Aderhold referred to the increase in transpiration caused by scab attacks, leading at times to the drying out of the shoots above the scabbed area.

Ducomet (1907) dealt in considerable detail with shoot infections. In his view the penetration into the cortex followed on the drying out of the epidermal layers. He recorded the formation in the host tissue of horizontally-extending fungus laminae which eventually forced off large plates of the bark and then fructified as described by Aderhold. The resulting desiccation of the shoot in the attacked areas was resisted by the formation of cork barriers underlying the infected cells. These barriers, however, were frequently unsuccessful in preventing the spread of the fungus, which broke through at weak points and formed fresh growth beneath the barrier. A further cork layer was then laid

* In the course of this investigation, assistance has, at different times, been received from Miss M. M. Walker, Mr. R. W. G. Dennis and Mr. H. C. Mellor, to whom the writer makes grateful acknowledgments.

down deeper in the tissues and the process repeated, possibly two or three times, until eventually the cutting off of the fungus was effected.

Salmon (1906) called attention to the prevalence of scab infection on the shoots of pears in this country. He recorded this type of infection on Doyenné du Comice, Marie Louise, Jargonelle, Beurré Diel, Beurré Bosc, Le Lectier, Doyenné Boussoch, Clapp's Favourite, Pitmaston Duchess and St. Germain. He pointed out that scab spread from the shoots not only to the leaves but also directly to the young fruit as soon as it was formed. The same author, with W. M. Ware, recorded in 1932 the presence of scab on the spur wood and bud scales of the pear.

OBSERVATIONS ON THE CYCLE OF INFECTION.

The varieties of pear seen by the author to be specially susceptible to shoot attack include Fertility, William's, Windsor, Louise Bonne, Summer Doyenné, Clapp's and Beurré d'Amanlis. Less susceptible varieties are Doyenné du Comice and Jargonelle. No scabbed shoots have been seen on Pitmaston, and Conference was not found infected until 1932, when a few scab pustules were seen on shoots of this variety.

Concerning the microscopic details of shoot infection, previous observations, particularly those of Aderhold and Ducomet, leave relatively little to be added. The accounts published by these authors, however, do not give the seasonal succession of the stages of infection and, in supplementing their observations, special attention has been directed to this point.

The first stages of shoot infection are similar to those described in an earlier paper on scab infection of apple shoots (Marsh and Walker, 1932).* As in the apple, a subcuticular infection first develops until the spread of the mycelium is directed beneath the external cell layer by the development of the normal epidermal cork. The pear fungus, however, shows more frequently the ability to penetrate cork in process of formation and can thus initiate infection at a considerable distance from the tip of the growing shoot. Having reached the underside of the bark the fungus spreads not only in the phellogen (as in the apple) but also in the collenchymatous layers of the cortex (Fig. 1). Here the tips of the hyphae become implanted in the thick wall cells and force their way along the line of the middle lamellae. The stouter portions of hyphae behind the tips wedge apart the adjoining cells, these eventually becoming entirely invested by the fungus. The penetration of the cortex is far more rapid in the tangential than in the radial direction and the final result is that a shallow stroma is formed which includes the remains of the disintegrated collenchyma tissue.

* It is intended that this 1932 paper should be read in conjunction with the present publication.

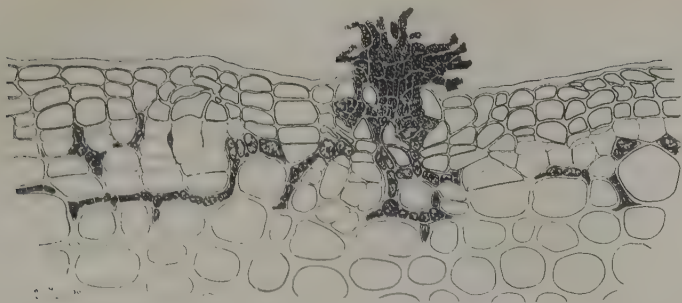


FIG. 1.

T.S. young infection 3 in. from tip of shoot of Fertility, 20.8.32. The mycelium has penetrated the normal cork in process of formation and is ramifying in the collenchyma and phellogen. Externally the fungus has formed a small group of conidiophores. (Stained iron alum-haematoxylin.)

The formation of such a primary infection takes place during the summer months and the shallow stroma thus produced may reach 2—3 mm. in length. On the flat external face, spore production takes place and small portions of the overlying bark may be split off, but there is not at this stage any production of tuberculate stromata or extensive flaking off of the bark.

The restriction in development of these primary stromata is due to the laying down of cork barriers before the end of the summer period of shoot growth. These barriers arise by the division of cortical cells beneath the infected area, and arrest the growth of the fungus by causing the drying-out and death of the tissues which they subtend. The barrier may bring about successful abscission of the infected area, or it may when incompletely suberized be penetrated radially by the fungus, or, more commonly, it may fail to unite

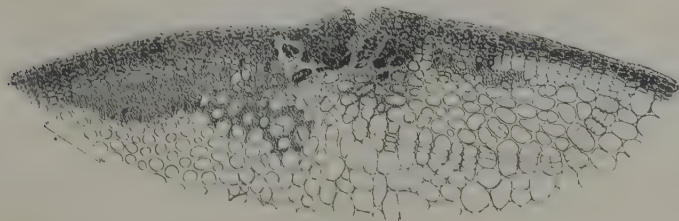


FIG. 2.

T.S. infection midway along shoot of Oldfield, 17.12.32. The break in the surface cork marks the original point of infection (compare Fig. 1). To the right, the fungus has made little progress and a new phellogen layer has arisen in the cortex. On the left, part of the collenchyma has been disintegrated by the mycelium, and a subsidiary pustule is forming below the bark. (Stained lacto-phenol cotton blue.)

with the normal cork at the perimeter of the infected area in time to prevent fresh extensions of the fungus from taking place. Such extensions arise more frequently in the direction parallel to the shoot axis than on the flanks of the primary pustule. Shoots examined in November commonly show the primary pustule withered or even absconded, with young subsidiary stromata beginning to develop under the bark bordering the ends of the original infected area (Fig. 2).

During the winter, no new cork formation takes place in the shoot, and the parasitizing of the host cells and growth of the subsidiary stromata is thus able to continue unimpeded. The fungal hyphae interpenetrate the cortical cells below, while above they form distinct columns of pseudoparenchyma, visible to the naked eye as a ring of protuberances forcing up the bark. By January spore formation is common on the sides of these columns, and at any time in the first three months of the year the pressure exerted by the growth of the fungus may force off large flakes of the overlying bark, these flakes being

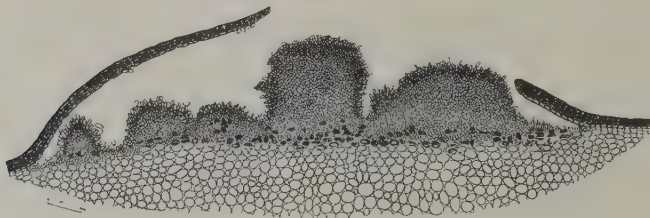


FIG. 3.

T.S. infection on shoot of Fertility, 24.3.31. The tuberculate stroma bursting open the bark has been formed by continued tangential and radial growth of a subsidiary pustule (see Fig. 2). The remains of partially digested cortical cells are embedded in the base of the stroma. Abundant spore formation is taking place, particularly on the peripheral, younger, portions of the fructification. (Unstained.)

at times a centimetre long. The fungus stroma is thus exposed with its numerous papillate spore-bearing structures united on a common base, as described by Aderhold (Fig. 3).

Although new spore-production on the pear shoots may start as early as January, the period of maximum spore dissemination is not reached until March or April. (Records relating to the spore output at this period are given in the section following.) Towards the end of April, the activity of the pustules is checked and eventually terminated following the renewal of growth by the shoots. With the commencement of secondary thickening in the spring, new phellogen formation starts and extensive cork barriers are laid down beneath the infected areas. These barriers arise usually in the inner cortex and the diseased area is cut off in part by the formation of the barrier and in part owing

to the splitting around the infected area consequent upon increase in girth of the healthy part of the shoot. By June, the abscission is usually complete and the diseased tissues carrying the fungus are shed, the site of the infection remaining as a concave, cork-lined scar.

RECORDS OF SPORE DISPERSAL.

1. *At Evesham.*

Records were taken in a commercial plantation at Evesham from March 30th to May 14th, 1931, and in the same plantation from March 23rd to May 11th, 1932. The plantation was made up of fifteen-year-old Fertility pears, in full bearing and making vigorous shoot growth, the shoots being heavily infected with scab. The technique of recording was as previously described (Marsh, 1931), vaselined slides being hung from the trees at 2 ft. 6 in. to 4 ft. above soil level. In these experiments no record was taken of the orientation of the slides exposed, but counts were made on both faces of each slide, the pairs of figures thus obtained being shown below separated by a plus sign.

In 1931 two slides were exposed from March 30th, when the blossom buds of Fertility were at the "burst" stage, to April 8th, when the buds were nearing the "green flower" stage. The resulting spore deposits were:

Slide 1.— 58 + 17 conidia per square inch.

Slide 2.— 9 + 7 " " " "

For the next series, April 8th to 21st, three slides were used and the results were as under:

Slide 1.— 228 + 350 conidia per square inch.

Slide 2.— 98 + 54 " " " "

Slide 3.— 752 + 94 " " " "

(Included in the 752 conidia on Slide 3 was a group of 165 found within an area of less than one millimetre diameter.)

The final series, of two slides, was exposed from April 21st—at the pre-flowering stage—until May 14th, when the petals of the Fertility blossoms were three-quarters fallen. No further records were taken, as a few infections of foliage were noted at this date. The records for this exposure were:

Slide 1.— 6 + 26 conidia per square inch.

Slide 2.— 38 + 140 " " " "

No ascospores were recorded on any of the slides mentioned above.

In 1932 each series of records was taken on three slides. The first three were placed in position on March 23rd, when the buds were almost at the

"bursting" stage, and removed on April 5th, when the buds were between "burst" and "green flower." The following were the results:

Slide 1.— 416 + 346 conidia per square inch.

Slide 2.— 1,170 + 36 " " " "

Slide 3.— 368 + 82 " " " "

The next series of records, for the period April 5th—18th, was as follows:

Slide 1.— 152 + 60 conidia per square inch.

Slide 2.— 100 + 38 " " " "

Slide 3.— 220 + 44 " " " "

Fresh slides were exposed from April 18th to April 27th, when the Fertility buds were just past the pre-flowering stage. The counts for this period were:

Slide 1.— 36 + 12 conidia per square inch.

Slide 2.— 30 + 22 " " " "

Slide 3.— 12 + 114 " " " "

The final exposures were made from April 27th to May 11th, with the following results:

Slide 1.— 26 + 42 conidia per square inch.

Slide 2.— 108 + 24 " " " "

Slide 3.— 28 + 136 " " " "

The results for the two seasons are summarized in Diagram I.

2. *At Long Ashton.*

A single trial was carried out at Long Ashton in 1931, making use of a standard perry pear tree (variety Oldfield), badly infected with scabbed wood and surrounded by overwintered leaves bearing abundant perithecia. Four slides were placed, 12 ft. to the east of this tree, at 1 ft. 3 in., 3 ft., 4 ft. 9 in., and 6 ft. 6 in. above soil level, respectively. Only the west side of each slide, directly facing the tree, was vaselined.

The exposure was made from April 15th to 22nd, and the counts resulted as follows:

<i>Height of slide above ground.</i>	<i>Number of conidia per sq. inch.</i>	<i>Number of ascospores per sq. inch.</i>
1 ft. 3 in.	454	0
3 ft.	476	0
4 ft. 9 in.	610	1
6 ft. 6 in.	752	0

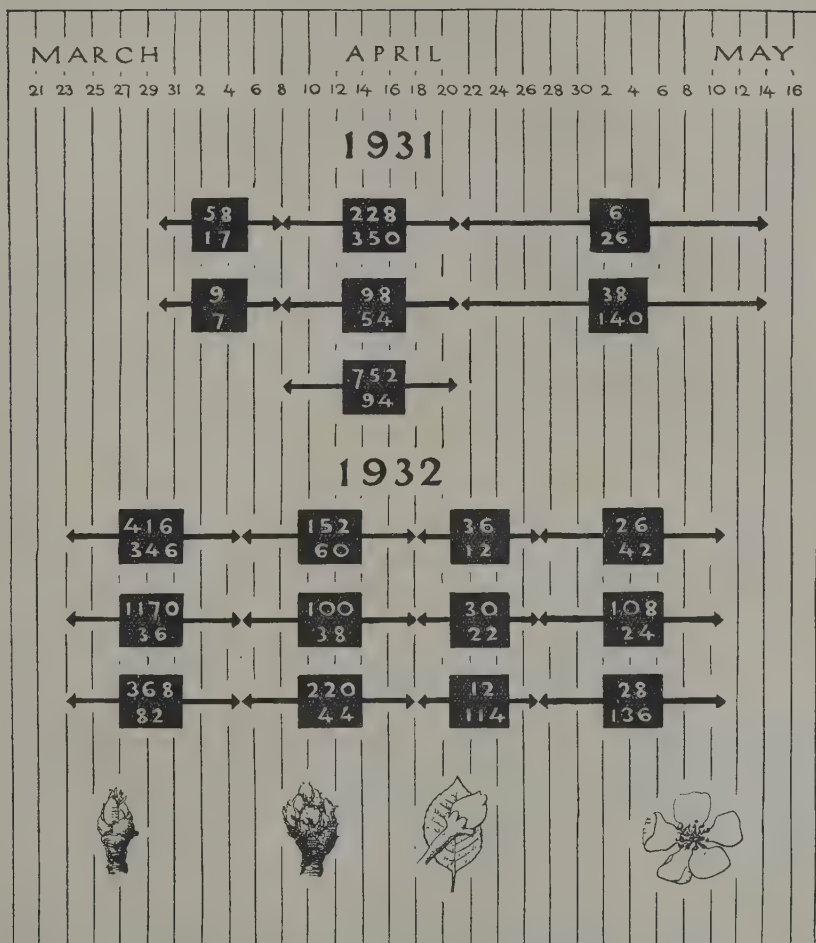


DIAGRAM 1.

Spore-trapping records at Evesham. For further details see text.

NOTE ON SOME FACTORS AFFECTING SPORE PRODUCTION ON SHOOTS.

The records given above indicate that the maximum production of conidia from the shoots takes place in April and late March. Conidia produced at this time show approximately 70 per cent viability. After April, the numbers and also the viability of the conidia produced from the shoots show a decline.

The rate of spore production in the spring falls still more rapidly on scabbed shoots removed from the tree. Scabbed shoots of Fertility cut off during pruning on March 30th and left lying in wet grass showed complete arrest of spore production by April 14th, due presumably to the drying-out of the infected tissues.

The possibility of checking infection by direct spraying of the fungus on the shoots has not been examined in detail but it may be noted in passing that spores were freely obtained from scabbed shoots of Fertility on April 22nd, 1932, ten days after these shoots had been heavily sprayed with 1 in 30 lime-sulphur. On testing, these spores showed 59 per cent germination. The successional development of the pustules and the close texture of the fungus stroma suggest that any direct attempt to kill scab on the shoots is unlikely to be successful.

SPRAYING TRIALS.

Spraying trials were carried out on approximately five acres of Fertility pears in a commercial plantation near Evesham. The trees were 15 years old, in full bearing, and planted in rows 15 feet apart, the trees being 15 feet apart in the rows. Each tree was trained on a modified espalier system, the adjacent trees of each row touching, so as to form a continuous hedge about 7 feet high and 1 foot thick, admirably suited for spraying.

This block of Fertility pears was included in a farm having approximately 200 acres of top fruit. The spraying equipment available for the whole consisted in 1931 of four 80-gallon barrow pumps, but in the winter of 1931-32 a 6 h.p. power sprayer was added. Lances were used in 1931 and spray guns in 1932.

1931 Season.

Following poor control in 1930, the trees of Fertility showed abundant scabbed wood in spring, 1931. Records of spore dissemination in this block are given in Diagram I and have been referred to above. A first spraying was carried out at the green flower stage, using Bordeaux 4-8-50, in the period April 12th—16th. The spraying was done with a barrow pump and lances, and on examination on April 21st it appeared that the cover obtained was poor. No other pre-blossom treatment was given but a single post-blossom spray was applied on May 16th—20th, using 1 in 60 lime-sulphur.

In the wet summer of 1931 this programme entirely failed to control scab. By mid-June approximately half the fruits were attacked and on July 28th a count showed that 68 per cent were scabbed. A month later, 95 per cent of the crop was badly scabbed and many of the cracked fruits were also invaded by brown rot.

1932 Season.

The provision of a power sprayer for the 1932 season made possible the carrying out of an adequate programme of thorough spray applications. Examination of the Fertility block in March showed that the amount of scabbed wood was at least as great as in the previous season and the spore-trapping records (see Diag. I) indicated that the amount of infective material was even greater than in 1931. No pruning was carried out until the beginning of April.

The record of spray applications made in 1932 is as follows:

Pre-blossom.

<i>Date.</i>	<i>Stage of blossom buds.</i>	<i>Spray fluid.</i>
March 23rd	nearly bursting	Bordeaux 4-8-50
April 5th	between burst and green flower	do.
April 27th	pre-flowering	do.

Post-Blossom.

<i>Date.</i>	<i>Spray fluid.</i>
June 6th	Lime-sulphur 1 in 60.
June 30th	do. do.
July 16th	Lime-sulphur 1 in 100.

A group of eight trees was left unsprayed throughout.

The weather was very favourable to scab attack during March, April and May, there being a succession of wet periods with relatively short breaks between. May, in particular, was a most difficult month for spraying, a rainfall of over six inches being accompanied by extensive floods in the Fertility plantation. The few fine days in this month barely sufficed for the spraying of the apple plantations so that the pears remained unsprayed from April 27th to June 6th.

During June, July and August the weather was generally hot and dry and spraying operations were carried out without difficulty.

On May 18th, abundant scabbed fruitlets were found on the unsprayed Fertility trees, but none on the sprayed block. The crop set well and a preliminary count on July 7th showed that the sprayed trees bore 82 per cent clean fruit and the unsprayed 5 per cent. A final count was made on August 17th when the fruits were graded as described in an earlier paper (Marsh, 1931). The results were as follows:

CATEGORY			<i>Sprayed.</i>	<i>Unsprayed.</i>
I.—Entirely free from scab	..		60%	2%
II.—Total scabbed area less than				
$\frac{1}{4}$ " square	.. ..		31%	23%
III.—Total scabbed area $\frac{1}{4}$ " to $\frac{1}{2}$ "				
square	.. ..		9%	50%
IV.—Total scabbed area $\frac{1}{2}$ " to 1"				
square	.. ..		—	25%

SPRAY DAMAGE.

The observations given below are fragmentary, but are put on record since very little information concerning spray damage on pears has been published in this country. The problem is far less pressing than that of spray damage in apples, as there is only one widely-grown variety which is frequently injured, namely Doyenné du Comice. This variety has been found damaged by post-blossom spraying with lime-sulphur at 1 in 30 (in Kent) and at 1 in 60 (in Worcestershire and Wiltshire). The damage takes the form of extensive leaf scorching and fruit drop. Damage to this variety has also been seen in Kent following the application of a post-blossom Bordeaux spray.

Slight foliage scorch following lime-sulphur spraying (both pre- and post-blossom) appeared at Long Ashton on practically all varieties in 1931 and 1932, but there was no resulting injury to the growth or to the crop.

At Evesham in May, 1932, a pre-flowering Bordeaux spray was followed by a scorching of the fruitlets and fruitlet stalks, very prevalent on Emile d'Heyst and noticeable on Fertility, Comice, Windsor and Louise Bonne. This damage took place during a period of unusually wet weather and is to be considered as exceptional. Although the badly scorched fruitlets were shed, the effect on the final crop was negligible.

Trials at Long Ashton in the past three seasons with lime-sulphur and with Bordeaux mixture used in April, May and June on some thirty pear varieties have not provided any additional records of regularly-occurring serious spray damage.

DISCUSSION.

In comparing scab attack of pear shoots with that on shoots of apple, it is a matter of general observation that the pear fungus infects more generally and penetrates more rapidly and extensively than the allied species. The lesions on the pear shoots in the spring are generally larger and the spore-producing capacity thus gained is increased by the tuberculate surface of the stromata. The shoots are thus able to act as sources of heavy infection for a period of several weeks.

The spore-trapping experiments at Evesham and Long Ashton provide a rough quantitative measure of the spore deposition on opening buds. These records demonstrate that shoot infections alone can provide amply for spring outbreaks of pear scab. As far as can be deduced from the evidence of these experiments, the likelihood of infection of the opening buds by ascospores is extremely slight.

During the period of bud unfolding from March to May, the scab spores have the opportunity of infecting the leaves and bracts, the sepals, petals, receptacles and flower stalks of the blossom buds. It has been previously noted (Salmon, 1906) that in the pear the infection of young fruits may come directly from wood infection and may be seen before any scab is visible on the leaves.

The infection of young shoots may take place earlier in the season than in the apple since the vegetative buds of the pear open almost as quickly as the fruit buds. Furthermore, the infection of young shoots—as of leaves and fruits—is more intense in the susceptible varieties of pear than in susceptible apples. Thus the prevention of the establishment of pear scab, both in spring and in summer, is undoubtedly more difficult than the control of the allied disease of apples.

A longer programme of sprayings than for the apple is inevitable, and, where pear trees are heavily infested with scab, much more than a single pre-blossom and a single post-blossom spraying is necessary. The details given earlier show the response to spraying of a badly-scabbed commercial plantation. Here, with a wet spring and a susceptible variety, six sprayings gave a crop 60 per cent free from scab as compared with 2 per cent on the controls. With less heavily infected material and more favourable conditions a lighter programme might suffice, but six or even more sprayings have in fact been regularly carried out in the last few years by the principal growers of pears in this country.

As most pear producers are also apple growers, the question of dovetailing the apple and pear scab spraying programmes will frequently arise. Supposing that both are to have two pre-blossom sprays, then the first pear spray would fall due towards the end of March, and the second pear spray and the first apple spray would both come roughly in the second week of April. The "pink" spray for apples would follow about the end of April and the first post-blossom spray for pears about a week later. If lime-sulphur were used throughout, the programme, with approximate dates, would then be:

March 30th—April 4th ..	pears	L.S. 1 in 30.
April 10th—20th ..	apples and pears	L.S. 1 in 30.
April 25th—May 4th ..	apples	L.S. 1 in 30.
May 1st—15th	pears	L.S. 1 in 60.

Later applications would be at 1 in 60 (or weaker) strength for all apples and pears not sensitive to sulphur damage.

The carrying out of such a programme requires, in most years, the fullest possible utilization of fine weather periods: this depends very largely on the provision of adequate spraying equipment.

SUMMARY.

An account is given of the successive stages of development of the scab fungus (*Venturia pirina*) in shoots of pear.

The results of spore-trapping experiments made in a badly-scabbed plantation are recorded. Dissemination of spores from scabbed pear shoots was found to be specially heavy in March and April.

Spraying trials made in 1931 and 1932 are described. Under conditions favourable to the disease it was found that two sprayings were useless, while six sprayings increased the proportion of clean fruit from 2 per cent to 60 per cent.

Notes on spray damage are added: particular susceptibility to sulphur and copper damage was recorded for Doyenné du Comice.

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POLLEN TUBE GROWTH IN DIPLOID AND POLYPLOID FRUITS

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INTRODUCTION.

It has been shown by Crane and Lawrence (1929-31) that in the Sweet Cherry (*Prunus avium*) self-incompatibility is of general occurrence. Cross-incompatibility is also common. The 38 varieties investigated by these authors are all self-incompatible, and 29 of them fall into 9 intra-sterile inter-fertile groups. Crane and Lawrence have also shown that in these fruits cross-incompatibility is always reciprocally expressed, that is, if A fails with B, B will also fail with A.

In the European plums (*Prunus domestica*) however, the behaviour of incompatibility is more complex. Different degrees of self and cross-compatibility occur, as well as complete compatibility and incompatibility. Moreover, cross-incompatibility is not always reciprocal. For example, the varieties President and Late Orange are completely self and cross-incompatible, and Cambridge Gage sets only about 3 per cent of fruit with its own pollen. Cambridge Gage further sets about 3 per cent of fruit when pollinated by President or Late Orange, but the pollen of Cambridge Gage results in a full crop of fruit in the reciprocal crosses.

In the apples (*Pyrus malus*), varying degrees of self-compatibility are found, but complete self and cross-incompatibility are rare. Only two varieties out of over forty tested failed completely upon selfing. Crane and Lawrence have also shown that variation in self-fertility is practically continuous.

The varieties investigated in the present study were:

Cherries :

1. Bigarreau Frogmore.
2. Governor Wood.
3. Bedford Prolific.

Plums :

1. Jefferson.
2. Seedling No. 1024.

Apples :

1. Cox's Orange Pippin.
2. Ellison's Orange.

In *Prunus*, the basic chromosome number is 8 (Knowlton 1924, Kobel 1927, Darlington 1928). The Sweet Cherries are diploid ($2n=16$) while the European

plums are hexaploid ($2n=48$). Cultivated apples are of two kinds, the so-called "diploids" and "triploids" with 34 and 51 chromosomes respectively. Cox's Orange Pippin is a diploid. The chromosome number of Ellison's Orange is not known, but its general characters indicate the probability of its being a diploid.

The present study was undertaken with a view to ascertaining the behaviour of incompatibility as expressed by pollen tube growth in some of these diploid and polyploid fruits.

TECHNIQUE.

Flowers of the varieties used as females were emasculated just as the petals started to open. They were pollinated when the stigmata were receptive, i.e., two or three days after pollen was ready. Flowers were examined for pollen tube growth from 3 to 15 days after pollination. The styles were dissected on a slide, and stained by Watkins' Cotton Blue method (1925). The cover slip was pressed gently to spread the tissues without injuring them, and the slide then examined.

OBSERVATIONS.

The maximum number of pollen tubes in the styles was found on the eighth day after pollination in plums, the sixth day in cherries and the fifth day in apples. The observations which follow were made on the results of these days.

CHERRIES.

The variety Bedford Prolific was selfed. As previously mentioned, all the cherry varieties are self-sterile, and this was clearly demonstrated to be the result of the failure of the pollen tubes to travel the whole length of the style and fertilize the ovules. When the selfed styles were examined, only two kinds of pollen grains were observed: (a) those which failed to germinate, and (b) those which penetrated the stylar tissue for a short distance only, the tubes then bending upwards and ceasing to grow. Diagrammatically the behaviour is illustrated in Fig. 1. The failure of the (a) class to germinate may be attributed to generational sterility, and the failure of the (b) class to travel the whole length of the style and effect fertilization to incompatibility.

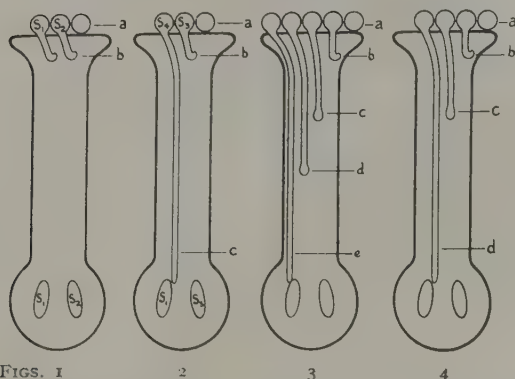
In the second place a cross was made between the variety Bigarreau Frogmore as female and Governor Wood as male. Here there were three types of pollen grains (Fig. 2), (a) those which did not germinate, (b) those which penetrated a short distance only, and (c) those which travelled the length of the style and reached the ovary. The classes a and b in this cross correspond to the classes a and b in the selfed styles of Bedford Prolific. An attempt to count the pollen tubes was found to be impracticable owing to their great number.

From the results of their investigations, Crane and Lawrence (1931) following the terminology of East and Mangelsdorf have shown that incompatibility factors can be assigned to the varieties here studied as follows:

Bedford Prolific S_1S_2 .

Bigarreau Frogmore S_1S_3 .

Governor Wood S_3S_4 .



DIAGRAMS OF COMPATIBLE AND INCOMPATIBLE POLLINATIONS.

- FIG. 1.—The behaviour of pollen grains in a selfed style of the cherry variety Bedford Prolific, showing complete inhibition of pollen tube growth.
- FIG. 2.—Style of the cherry variety Bigarreau Frogmore crossed with pollen from Governor Wood. Pollen tubes are either completely inhibited or grow the full length of the style.
- FIG. 3.—Different grades of pollen tube growth in the style of the plum variety Jefferson crossed with the John Innes seedling 1024.
- FIG. 4.—Various grades of pollen tube growth in a style of the apple variety Cox's Orange Pippin crossed with Ellison's Orange.

It is probable that the b class observed in the selfed styles of Bedford Prolific comprises both S_1 and S_2 gametes, and the b class in the styles of Bigarreau Frogmore $\times$ Governor Wood comprises S_3 gametes only. The S_4 gametes would be the c class which travel the full length of the styles and effect fertilization.

PLUMS.

A cross was made between the variety Jefferson as female and the seedling 1024 as male. [No. 1024 (J.I.H.I. number) is a seedling from the cross Comte d'Althan $\times$ Jefferson. Seedling 1024 entirely fails to set when crossed with Jefferson, but the reciprocal cross gives a full crop of fruit.] In this cross there were five different classes of pollen which were observed in each style examined (see Fig. 3). (a) Those pollen grains which did not germinate, owing to generational sterility, (b) those which developed a short pollen tube which

ultimately bent upwards and stopped growing, (c) those which grew about a quarter of the length of the style, (d) those which grew to approximately half the length of the style, and finally (e) those which travelled the full length of the style and effected fertilization.

A question at issue is whether the differential rates of growth of the various pollen tubes are due to differences of genetic constitution? If this is the case, evidently selective fertilization would result. It might be argued that the difference in length of the various pollen tubes is due largely to variation in the time of germination; that those pollen grains which are in intimate contact with the stigma absorb its secretion and put forth their tubes more quickly than those less favourably situated. In the plums, styles were examined every day from the third day after pollination to the fifteenth. Thus all types of pollen grains, even the slowest, were given a good chance of full growth, yet in every case, all the five types of behaviour of pollen tubes were observed. Thus selective fertilization is at work, and it becomes highly probable that the observed differences in pollen tube growth are due to differences in genetic constitution. It is obvious that this behaviour is more complex than in the cherries.

APPLES.

A cross was made between the varieties Cox's Orange Pippin as female and Ellison's Orange as male. There were four types of pollen grains (Fig. 4), (a) those which did not germinate, through generational sterility, (b) those which put forth a short tube which bent upwards and stopped growing, (c) those which grew to approximately one-third of the length of the style, and (d) those which penetrated the full length of the style and reached the ovary. The same argument holds for the apples as for the plums and the evidence points to selective fertilization due to differences in the genetic constitution of the pollen grains.

DISCUSSION.

Incompatibility is a phenomenon of widespread occurrence among plants, and has been intensively studied by a number of investigators. East and his collaborators (1925, 1926), Lehmann (1926), and Sirks (1926, 1927), working with different plants concluded that there was a series of multiple allelomorphs which acted in such a way that if the female sporophyte carried similar factors to those of the pollen tubes, fertilization did not take place. As pointed out by Crane and Lawrence, the behaviour of polyploids in this respect is more complex than that of diploids.

The present study throws light on the behaviour of incompatibility as expressed by pollen tube growth in diploids and polyploids respectively. The

cherries used in these investigations are diploids, and the observed behaviour of pollen tube growth agrees with disomic expectation. By crossing Bigarreau Frogmore with Governor Wood, apart from the pollen grains which did not germinate, owing presumably to the generational sterility which is frequent throughout these fruits, two kinds of pollen were produced, (a) with a short tube that did not continue growth and (b) with a tube long enough to effect fertilization. This, therefore, is a case of a sharp distinction between complete inhibition and non-inhibition of pollen tube growth in a diploid.

The plums investigated are hexaploid varieties and therefore we may be concerned with six incompatibility factors. As a result a greater number of gametic types both of pollen grains and ovules may occur. When Jefferson was crossed with Seedling 1024, different grades of pollen tube growth were observed. On the hypothesis that the rate of growth will vary in proportion to the ratio of like to unlike factors in the female, in the pollen and between the two, it follows that these differential ratios would result in differential pollen tube growth with several gradations between a minimum and a maximum rate of growth.

Cultivated apples, as mentioned above, are of two kinds with 34 and 51 chromosomes respectively. If Cox's Orange and Ellison's Orange were simple diploids, each gamete would be expected to carry only one incompatibility factor, and thus in a cross between these two varieties one would expect a behaviour similar to that of the cherries. In this cross, however, various grades of pollen tube growth were observed; this can be explained on the basis of the cytological assumption put forward by Darlington and Moffett (1930) and Moffett (1931) that these apples are actually secondary polyploids.

Clearly, therefore, in the diploid cherries, the behaviour of incompatibility is fairly simple; no intermediate grades of growth occur. Pollen tube growth is either totally inhibited or not inhibited at all. In plums and apples, which have been proved cytologically to be polyploids, the incompatibility behaviour is far more complex, with greater variation in pollen tube growth. Therefore the expression of incompatibility is more complex and variable in polyploids than in diploids. This may be accounted for by the polymeric condition of the factors which determine incompatibility in polyploids.

SUMMARY.

1. Pollen tube growth was studied in cherries, plums and apples. These fruits are diploid, hexaploid and secondary polyploid respectively.

2. In the diploid cherries ($2n=16$), three types of pollen grains were observed, (a) those which failed to germinate, probably owing to generational sterility, (b) those which produced a very short tube which bent upwards and

stopped growing, and (c) those which travelled the whole length of the style and effected fertilization.

3. In the hexaploid plums ($2n=48$) five kinds of pollen grains were observed, (a) those which did not germinate, (b) those which developed a short tube which ultimately bent upwards and stopped growing, (c) those which grew about a quarter of the length of the style, (d) those which grew to about half the length of the style, and (e) those which reached the ovary.

4. In the apples, four types of pollen occurred: (a) pollen grains which did not germinate at all, (b) those with a short tube which turned upwards and stopped, (c) those which grew to approximately one-third of the length of the style and (d) those which reached the ovary.

5. It is concluded that the behaviour of pollen tube growth in these fruits is strictly correlated with their genetical and cytological constitution.

6. The results obtained in apples support the theory postulated by Darlington and Moffett as to the secondary polyploid constitution of these fruits.

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THE POTASSIUM STATUS OF SOILS AND FRUIT PLANTS IN SOME CASES OF POTASSIUM DEFICIENCY

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In previous communications in this Journal (15, 16) it has been shown by one of us that potassium deficiency of fruit trees in this country is a major problem of fruit tree nutrition. The widespread occurrence of the deficiency, the relation of its incidence to certain soil characters, and its main effects on various classes and varieties of fruits have been indicated; experiments have been described showing the beneficial effects of potassic manures and of dung; and it has been shown how the deficiency is reflected in the chemical composition of various portions of affected plants.

During the course of these investigations, it has been clearly evident that there exist some very special problems in relation to potassium deficiency of fruit trees. Thus it has been demonstrated again and again that many classes of fruit trees fail entirely to make healthy growth, due to potassium starvation, on sites where ordinary agricultural crops, including cereals, root crops and clover have previously been grown successfully.†

From such observations, it would appear that the trees are unable to obtain sufficient potassium to supply their needs under conditions where agricultural crops are efficiently supplied. This position raises the whole question of possible differences between the requirements and feeding powers of the two classes of plants. Have fruit trees much larger requirements for potassium than agricultural plants? Are they unable to extract from the soil certain forms of potassium which agricultural plants are able to obtain? Or is the main difference due to the deeper rooting habits of fruit plants, leading to the result that trees must of necessity extract much of their potassium supply from subsoil layers, where the amounts of readily available potassium, as shown by chemical tests, are much less than in the surface horizon (8, 14).

In connection with the problem of the actual feeding powers of fruit plants, it is a common observation that when large trees or even bush fruits are

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† See Ref. 13 for a typical example.

removed from plantations after several seasons of growth, the soil is frequently comparatively infertile and much time has often to elapse and heavy manuring to be practised to restore the fertility of the areas.

At the present time, it cannot be said that authoritative answers can be given to any of the above questions and, in view of both the theoretical and practical importance of the problems, it seems necessary to pursue various aspects of them as opportunities occur. The final solution of the general problem is not likely to be reached in the near future since it involves considerable practical difficulties in the studies which will be necessary in relation to root distribution, soil chemistry and the growing of trees under controlled laboratory conditions.

In the present series of investigations the writers set out to examine two aspects of the problem:

1. Whether plants such as buckwheat and tomato behaved in similar fashion, as regards potassium nutrition, as did apple trees on two soil areas, on one of which the apples were total failures due to potassium deficiency whilst on the other the trees apparently obtained sufficient potassium to maintain healthy growth: what forms of the soil potassium did the buckwheat and tomato plants utilize in these soils?
2. The potassium status of soils and fruit plants in some well marked and proved cases of potassium deficiency and the effects of potassic manures on the soil and plant contents of the element.

The results of the investigations relating to the former point are contained in another paper (13). They show that the results with the buckwheat and tomatoes were dissimilar from those with the apple trees and that the tomatoes were apparently able to secure potassium present in a non-exchangeable form from the soils.

For the purpose of the latter investigations, twenty-three centres were selected, eleven of apples, eight of plums and four of bush fruits, including three of gooseberries and one each of black and red currants.

The special objects of the work have been as follows:

1. To determine the amounts of potassium in the surface soils (and a few subsoils) of potassium deficient areas present as (a) water extractable, using soil/water ratio of 1:1; (b) soluble in 1 per cent citric acid, using Dyer's technique; (c) replaceable, using ammonium acetate as leaching agent.
2. To examine the effects of dressings of potassic manures and of dung on the supplies of the above forms of potassium in the soils and subsoils.
3. To relate the potassium supplies in the soils, before and after manuring, with the contents of the element in the plants at these periods.

HISTORICAL.

Numerous investigations have been carried out in the past with the object of attempting to evolve laboratory tests which will provide guidance as to the potassium supplying powers of soils and, although certain of the methods which have been developed have been found capable of useful practical application, they are still all more or less empirical and not based on a full knowledge of the availability to plants of the various forms of potassium which occur in the soils.

In these studies it has been generally recognized that soil potassium exists in many different forms and it has been usual to divide it into the following categories:

1. Water soluble, i.e., present in the soil solution or in water extracts.
2. Extractable by steam under pressure.
3. Soluble in weak acids, such as 1 per cent citric acid, 0.2 per cent HNO_3 , $\frac{N}{20}$ H_2CO_3 , etc.
4. Replaceable, i.e., present in the colloidal complex and removable by leaching with salt solutions.
5. Soluble in strong acids.
6. Insoluble in strong acids.

In addition to these methods, attempts have been made to determine potassium available to plants by physiological methods such as Neubauer's Seedling method (10).

With regard to the various chemical methods, it is generally assumed that water soluble potassium is wholly available to all plants, but here the question arises as to whether the important point is not so much the concentration of potassium present in the soil solution at any given time but the power of the soil to maintain an adequate concentration over considerable periods. Comber (3) has suggested that plants may also absorb foodstuffs directly from the colloidal complex apart from the soil solution.

Several investigations have been carried out to determine the minimum concentrations of potassium required in culture solutions to produce optimum growth conditions with various plants and it has been usual to find that, provided concentrations are maintained throughout the growth period, the amounts necessary are quite low. Thus Parker and Pierre (12) obtained optimum growth of soybeans with 2.0 parts per million of potassium, which value was also perhaps correct for corn; Bartholomew and Janssen (1) obtained the following values—for tomatoes 3.0 to 5.0 parts per million, Sudan grass 3 parts per million, cowpeas, soybeans, and cotton 2 parts per million; alfalfa and Hubam clover 0.5 parts per million; Johnson and Hoagland (7) decided that 5.0 parts per million was the approximate value for tomatoes.

Of the weak acid solvents, Dyer's 1 per cent Citric Acid Method has perhaps proved the most generally useful in practice. Stewart (14) and Wheating (17) both found that results by this method showed good correlation with the

Neubauer Seedling method and replaceable potassium values, and Stewart indicated the relationship which may be expected between the three methods when considered in the light of base exchange phenomena.

The majority of investigators consider that the "replaceable" value provides the soundest basis for considering available potassium supplies, as this category of the element represents a more or less distinct class of soil potassium, the amount present in the absorbing complex. Moreover, there is considerable evidence now available to show that this fraction of the soil potassium is readily available to plants. Thus it has been found that the quantity corresponds closely with the amount of potassium removed by seedlings in the Neubauer test (14); Joffe and McLean (6) used replaceable potassium in a soil as the sole source of potassium to plants with success; Nostitz (11) supplied potassium by permutites containing the element in the base exchange complex; Martin (9) demonstrated the losses in replaceable potassium from continuous cropping with barley, 12 crops depleting the replaceable supplies to the extent of 30 per cent to 70 per cent with various soils. Moreover, he showed that in the cases of heavy soils 80 per cent of the potassium taken up by the plants could be accounted for by losses of replaceable potassium and on the light soils the value was 85 per cent.

The complications in the use of replaceable potassium as an absolute index arise from the fact that, as pointed out by Gedroiz (4), replaceable potassium can only be "practically, completely removed" and thus cannot be "absolutely" determined whilst there is also evidence that some plants utilize "non-replaceable" potassium. Thus Gedroiz was able to grow oats, mustard, and buckwheat in a soil from which all the replaceable potassium had been replaced by calcium without adding further supplies of potassium. Martin (9) also obtained evidence of barley using non-replaceable potassium on light soils of "low replaceable" potassium content whilst Hoagland and Martin (5) state that from their experiments "they have gained the impression that the non-zeolitic minerals assist in maintaining physiologically important concentrations of potassium in soil solutions." Proebsting (13) obtained evidence of tomatoes utilizing non-replaceable potassium. Bauer (2) has also shown that sweet clover is able to obtain potassium from orthoclase feldspar.

The amounts of potassium soluble in strong acids and the quantities of total potassium in soils do not show correlations with any of the previously discussed forms of potassium (8, 14) and such determinations are considered of little value as an aid to understanding the potassium supplying powers of soils.

Lilleland and Stewart have reported results of soil investigations which are of particular interest in connection with the present studies. Those of Lilleland (8) have been similar to our own, having been concerned with the distribution of water-extractable (1:1) and replaceable potassium in orchard soils

in California in connection with cases of potassium deficiency of prunes. Two important points were brought out in the results, viz., that the amounts of water soluble and replaceable potassium decreased with depth in all cases and the values for replaceable potassium from about 4 feet to 8 feet deep were similar for all the soils examined in spite of large differences in values for the surface horizons. These facts are possibly of great significance in the problem of available supplies of potassium to fruit trees if it is subsequently shown that the plants rely mainly on replaceable potassium as a source of supply of the element. Stewart (14) also showed decreases in citric soluble and replaceable potassium with depth, his average values for 12 Scottish soils being as follows:

Citric Soluble K ₂ O	..	..	Surface soils	0.0086%
			All horizons	0.0074%
Replaceable K ₂ O	..	..	Surface soils	0.0161%
			All horizons	0.0135%

It will be evident from the foregoing review that in soil studies of potassium supplies, determinations of replaceable potassium appear to form a suitable starting point and that points of interest may reasonably be expected to emerge from determinations of citric soluble and water extractable amounts of the element.

EXPERIMENTAL.

The Centres. The centres selected for the investigations were chosen as providing representative and well marked cases of potassium deficiency from widely separated districts and as exhibiting a variety of soil conditions. In nineteen of the twenty-three cases, extensive experimental work relating to the action of manures on growth, cropping, quality of the fruit and chemistry of the trees and bushes has been carried out so that the extent of the deficiency effects and the action of manures have been ascertained in great detail. In the other four cases, Centres 3, 11, 12, 19, the effects of the deficiency were all strongly marked and offered no difficulties as to diagnosis etc.

The majority of the cases considered relate to apples, mainly because this class of fruit has provided very striking and difficult cases of the deficiency, necessitating much field experimental work; plums occupy the second position of importance and with this fruit the cases mostly refer to the variety Purple Pershore which has shown itself as particularly susceptible to shortage of potassium; only four centres for bush fruits are considered and these include three cases of gooseberries and one each of black and red currants.

The relevant details relating to the location of the centres, the characters and growth features of the trees, general soil properties and management details are assembled in Table I.

TABLE I.
General Notes on Centres.

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
APPLES. 1	Herefordshire.	Gentle slope to S.E.	Bush trees, vars. Worcester Pearmain and James Grieve on Mallings No. 1 stock. Affected with leaf scorch and much stunted for several years prior to potash manuring. Also liable to show symptoms of nitrogen deficiency unless cultural conditions high and small dressings of nitrogenous manures given.	Parent material: coarse grained red sandstone of Old Red Sandstone formation. Texture generally coarse-grained loamy sand to depth of several feet but at points of poorest growth soft sandstone rock at 1'. Drainage free to excessive.	Good, but cultivation on low side which has resulted in trees showing symptoms of low nitrogen. Previous manuring usually with nitrogen and phosphates.
2	Herefordshire.	Gentle slope to W.	Half standards, vars. Stirling Castle, Worcester Pearmain, Newton Wonder, all head worked on Warner's King and other old varieties. Seedling stocks. All trees at 20 years total failures and several dead following leaf scorch. Newly planted trees and the better of the old planting—also plums—have grown well with adequate potash manuring.	Parent material: mixture of red marl and red sandstone with soft sandstone rock at 30". Old Red Sandstone formation. Texture to 18" fine sandy loam then passing into loamy sand on rock. Drainage free.	Good in all respects. Previous manuring, phosphates and lime.
3	Herefordshire.	Top of knoll with gentle slopes.	Half standards on seedling stocks, vars. Worcester Pearmain, Cox's Orange Pippin, Newton Wonder. Total failures after 20 years and many dead. Leaf scorch very severe.	Parent material: Old Red Sandstone marl. The marl is very tough and platy in structure. Soil poorly weathered, often only to a depth of 1' to 18". Heavy fine sandy silty loam, liable to waterlog in wet periods and to dry out during dry times.	As No. 2.
4	Worcestershire.	Very gentle slope to S.	Bush trees, var. Early Victoria on Mallings No. 1 stock. Growth after about 16 years very patchy; areas of total failure, with leaf scorch and dying out of trees, and others where growth fairly healthy.	Parent material: River Terrace mainly of Bunter Sand and pebbles mixed with Lower Lias Clay, passing into calcareous Lias Clay at varying depths, generally below 3'. Texture varies from light sandy loam to heavy loam. Drainage only fair owing to underlying clay.	Market garden and bush fruit crops grown in alleyways and manuring inclined to be of high nitrogen type. Management of the trees only moderate.

TABLE I (continued).

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
APPLES. 5	Somerset.	Level.	Bush trees, var. Lane's Prince Albert on Malling No. 2 rootstock. Plantation is used for a manurial experiment. At planting areas of good and bad growth noted, the latter being associated with severe symptoms of potassium deficiency. Trees on previously bad areas reacting well to potash manuring after 3 years of treatment. Gooseberries interplanted recently showed severe leaf scorch during first season both on better and poor areas where no manure or "omit potash" treatments followed.	Parent material: red sand-marl mixture (colluvial) over red marl, all derived from Keuper formation. Texture to 30" fine sandy loam. Drainage good.	Good, all respects. Cultivation high.
6	Kent.	Level.	Bush trees, several varieties on seedling and "Paradise" stocks, used in Pruning Experiment. Later used to test potash manuring on leaf scorch. (See Grubb, N. H., <i>J. Pomol. & Hort. Sci.</i> , Vol. VII (1928-29).)	Parent material: River Terrace mainly of Lower Greensand (Hythe Beds) material over Sedimentary Hythe Beds. Soil fine sandy loam with rock occasionally at 30". Drainage good.	Good, all respects. Cultivation and manuring (especially with N) originally high. Portion of area grassed down since 1930 and experimental potash dressings to parts of plot since 1923.
7	Kent.	Level.	Bush trees, vars. Bramley's Seedling and Worcester Pearmain on various Malling stocks. Planted 1920. (See Amos, J., Hutton, R. G. and Hoblyn, T. N., <i>Proc. Assn. Econ. Biol.</i> , Vol. XVII (1930), p. 657.)	As No. 6.	Good in all respects. Experimental manurial treatments: one half no manure and other complete manure annually since planting.

TABLE I (continued).

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
APPLES. 8	Lancashire.	Level.	Bush trees, vars. Grenadier and Bismarck on "Paradise": planted 1912. Comprise a manurial experiment with treatments farmyard manure, complete artificials, nitrate of soda and potassium sulphate. On "nitrate only" plot severe stunting and leaf scorch has persisted throughout experiment. Scorched trees have reacted to sulphate of potash.	Parent material: Superficial deposit (River Gravel) pebbly sand—clay mixture of mixed origin, probably mainly Triassic. High organic matter content. Drainage good.	Good, all respects. Manurial treatments experimental.
			Bush trees, vars. James Grieve and Lord Derby on "Paradise." Up to 17 years growth patchy, from stunting to fairly good, and all affected to some extent with leaf scorch.	Parent material: red marl of Keuper formation. Soil medium to heavy fine sandy-silty loam. Drainage fair, with somewhat wetish patches.	Generally good, but manures only very sparingly applied and never potash manures.
10	Kent.	Level.	Bush trees, vars. Lane's Prince Albert, Beauty of Bath, Gladstone, Newton Wonder, Bramley's Seedling, Allington Pippin and Blenheim Orange Pippin. All varieties for many years almost total failures and many dying out due to potassium deficiency. Great improvement has followed heavy experimental K_2SO_4 dressings.	Parent material: mainly fine textured Brick Earth with some admixture of Chalk. Overlies Chalk but this not within root range. Drainage free.	Good, but prior to potash experiments, manuring mainly with nitrogen and phosphates. Grass system of cultivation since 1927.
			Bush trees, stocks unknown, var. Allington Pippin about 10 years old. Trees dying back in patches and show leaf scorch. Black currants between the apple trees have made healthy growth.	Parent material: red marl of Old Red Sandstone origin. Soil poorly weathered, heavy fine sandy-silty loam with unweathered material from 9" depth. Liable to lie wet in wet periods and to dry out in dry times.	Moderate. Cultivation satisfactory. Manuring given to the black currants.
PRUNES. 12	Herefordshire.	Top of knoll. Very gentle slope.	Half standards, var. Blaisdon Red. Only 3 or 4 years planted. Leaf scorch and stunting severe in patches.	As No. 1, but sandstone generally within 18" of surface. Drainage free to excessive.	Good in all respects except adequate potash not initially given.

TABLE I (*continued*).

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
Pums. 13	Worcestershire.	Level.	Half standards, var. Purple Pershore. Probably approximately 20 years planted. Intercropped with vegetables and these usually heavily manured with nitrogen and phosphates. Most trees show severe potassium deficiency effects; few fairly normal.	Parent material: River Terrace mainly of Bunter Sand and gravel with some clay patches. Texture a sandy loam with heavier patches in subsoil. Drainage moderate and liable to lie wet.	Operations on trees secondary to those for market garden crops, resulting in only moderate care of the trees. Potash manuring neglected until recently.
14	Worcestershire.	Level.	Half standards, var. Purple Pershore. Age over 20 years. Intercropped with vegetables which receive dressings of nitrogenous manures. Growth of trees patchy and all trees show potassium deficiency to some extent.	As No. 4.	Moderate. Operations primarily concerned with the vegetable crops. No potash manures given.
15	Worcestershire.	Near foot of medium slope.	Half standards, var. Purple Pershore. Age approximately 20 years. Intercropped with vegetables which are heavily manured with nitrogen and phosphates. Spraying with 1% K_2SO_4 has produced some response.	Parent material: edge of a River Terrace and mixture of Bunter Sand and gravel with Lias Clay over Lower Lias Clay. Texture of soil sand-clay with clay usually at 2'. Drainage moderate to poor.	Good, but manuring determined by needs of vegetable crops. Potash not given.
16	Worcestershire.	Gentle slope to W.	Half standards, var. Purple Pershore, over 20 years. Growth very patchy due to leaf scorch, and on one area trees severely stunted. Normal growth only on very small proportion of the area. Black currants previously interplanted and grew strongly and carried heavy crops. Plums have responded to heavy K_2SO_4 dressings.	Parent material: brown mudstone from the Wenlock Series. Soil texture medium fine sandy-silty loam, shallow in parts and only poorly weathered. Unweathered material in places at 1' depth. Drainage good.	Good intensive management. Black currants heavily manured with nitrogen and phosphates and a little "stable" manure. Potash not applied previous to manurial experiment.

TABLE I (continued).

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
PLUMS. 17	Herefordshire.	Practically level and at foot of slope.	Bush trees, var. Purple Pershore, on Yellow Pershore stock, planted 1920. Also pears, vars. Conference and Fertility. All fruits have been practically failures due to potassium deficiency and area has always had a bad reputation for fruit. Trees have reacted to heavy K_2SO_4 dressings.	Parent material: colluvial red sand of Old Red Sandstone origin. Texture fine sandy-silty loam. Soil deep. Drainage good.	Good in all respects. Previously heavily manured with nitrogen and phosphates and some low quality stable manure. Potash manures given in experiment during past few years.
18	Herefordshire.	Gentle to medium slope to W.	Half standards, var. Purple Pershore. Approximately 10 years. All severely stunted and showing strong potassium deficiency. Have reacted markedly to K_2SO_4 dressings.	Parent material: mainly colluvial red sand and marl of Old Red Sandstone origin with slight admixture of Silurian Mudstone material containing limestone fragments. Texture fine sandy-silty loam. Soil of good depth. Drainage good.	Good. Previously high cultural and manurial conditions practised. Latterly cultivation lowered to weedy state. Manures previous to K_2SO_4 experiments mainly nitrogenous.
19	Worcestershire.	Gentle slope to S.E.	Half standards, var. Purple Pershore, approximately 10 years. All show potassium starvation and many definite stunting.	Parent material: alluvium mainly of Old Red Sandstone red marly material. Texture fine sandy-silty loam. Soil deep. Drainage good.	Good, but no potash manures applied.
BUSH FRUITS. 20	Somerset.	Gentle slope from N.W. corner to S.E.	Gooseberries, var. Keepsake. Planted 1921 and area used for a manurial experiment. (See Wallace, T., <i>J. Pomol.</i> , Vol. 6, p. 184 (1927).) Severe potassium deficiency has persisted throughout experiment (i.e. to 1932) where potash manures not given.	Generally as No. 5. Better patches more marly and poorer areas more sandy.	Good. Manurial treatments experimental.
21	Somerset.	Practically level.	Black currants, var. Baldwin. Planted 1927-28. Used as manurial experiment. Potassium deficiency to medium extent on all plots where potash not applied.	As poorer areas of No. 5.	Good. Manurial treatments experimental.

TABLE I (continued).

Centre No.	Locality.	Site.	Particulars of Trees, or Bushes.	Soil Characters.	Management.
BUSH FRUITS. 22	Worcestershire.	Practically level.	Gooseberries, var. Careless and few Whinham's as rogues. Planted 1921 and until 1927, severe scorch over area with patches where bushes almost total failures. Bushes have reacted well to K_2SO_4 , but not to lime, although soil is acid. Nitrogen also gives a reaction when potash deficiency has been remedied.	Parent material: River Terrace composed mainly of Bunter Sand and gravel over Lias clay. Soil shows podsollic features with distinct iron pan formation in patches. Texture loamy sand. Drainage free.	Moderate. Cultivation rather rough and very little manuring done prior to experimental treatments, from 1927.
23	Kent.	Elevated and level.	Red currants, gooseberries and young plums and cherries. Bush fruits 2 years planted and all stunted and severely scorched. Excellent response of gooseberries to two dressings of K_2SO_4 at 4 cwts. per acre but practically no response of red currants.	Parent material: Combe Rock, very flinty, over Chalk at varying depths. Texture fine sandy loam with many flints. Drainage free.	Good. Mangels grown between bushes and the root crop dressed with "complete fertilizer."

Methods of Soil Examination. The soil samples examined were mainly of the surface 9" but in a few cases subsoil samples were also obtained between the depths of 9" to 18". The depths are thus merely the conventional English surface and subsoil depths and bear no relation to the actual horization of the soils. The problem of selecting sampling depths for studies involving comparisons is particularly difficult in orchard soils in this country where cultural practices show such a large range of variation.

At several centres it was possible to obtain samples from areas to which no potassic manures had been applied for many years—often during the whole period that the land had been under fruit—and from others where known amounts of sulphate or muriate of potash or of farmyard manure had been applied for definite periods prior to sampling. The potash treated plots also comprised some to which the manurial dressings had been very heavy over periods of years immediately prior to sampling and others to which only single or small applications had been made. Such cases have made it possible to follow the changes undergone by the soluble potash salts subsequent to their incorporation with the soils. In all cases shown in the tables in which soil data are given for manured plots, the soil samples were taken during the summer of 1931.

For the chemical determinations, air dried samples of soil, previously ground to pass through a 2 mm. sieve, were used.

The 1:1 water extracts were prepared by adding sufficient water to air-dried soil to make 100 gms. each of soil and water. The mixture was then shaken intermittently for several hours, allowed to stand overnight and filtered through a Buchner filter.

The replaceable base extracts were prepared by shaking 50 gms. soil with 200 c.c. normal neutral ammonium acetate, following the same general procedure as adopted for the water extracts. Additional ammonium acetate was leached through until the filtrate amounted to 500 c.c.

A modification of the Briggs colorimetric method was used for the subsequent estimation of potassium in both extracts.

For the determination of citric soluble potassium, the usual Dyer procedure was followed, using 200 gms. soil, 20 gms. citric acid and 2,000 c.c. water, the extraction being carried out in a Winchester which was shaken at intervals over a period of seven days. The perchlorate method was employed for the estimation of potassium in the extracts.

Data on Plant Material. The data available on plant material refer to portions of terminal shoots and fruit pulp. In many cases they are a selection from a large mass of data collected during the course of intensive investigations carried out over several seasons. The presentation of the complete data in such cases would have been very inconvenient owing to their bulk, and is also

unnecessary, since the examples given illustrate faithfully and clearly the essential points of the results. Terminal shoots and fruit pulp were selected for examination as it has been shown previously that deficiency of potassium, where it occurs, is clearly reflected in these parts (16).

The data include comparisons of material for "Better" and "Poorer" trees growing on potassium deficient areas, and also from unmanured and manured plots where potassium deficiency is strongly developed in the former cases.

RESULTS.

Soil Data. The salient features of the soil data are summarized in Tables II and III. In the former table, the whole of the data relating to the potassium determinations made on the soils from all centres is presented and values for total nitrogen where these are available are also given.

The centres are arranged in groups according to the class of fruit concerned and the special manurial features are shown, whilst the data relating to potassium include the values for water extractable, citric soluble and replaceable amounts, and the ratios of these to each other.

From the data relating to the surface soils of unmanured areas, the ranges and average values for the three forms of potassium have been determined under the three groups, apples, plums and bush fruits, and the averages for water extractable and citric soluble have been calculated as percentages of the corresponding values for the replaceable form. The results are as follows:

Apple Centres:

(15) Water Soluble:

range 17.0 to 1.6 p.p.m. ; average 4.5 p.p.m. ; % of replace: 2.2

(14) Citric Soluble:

range 137 ,, 38 ,, ; ,, 84 ,, ; ,, ,, : 42

(15) Replaceable:

range 360 ,, 100 ,, ; ,, 201 ,, ; —

Plum Centres:

(5) Water Soluble:

range 2.3 to 0.6 p.p.m. ; average 1.6 p.p.m. ; % of replace: 1.3

(5) Citric Soluble:

range 69 ,, 45 ,, ; ,, 58 ,, ; ,, ,, : 45

(6) Replaceable:

range 190 ,, 90 ,, ; ,, 128 ,, ; —

Bush Fruits :

(7) Water Soluble :

range 4.6 to 2.0 p.p.m. ; average 3.4 p.p.m. ; % of replace : 2.0

(6) Citric Soluble :

range 183 ,, 47 ,, ; ,, 86 ,, ; ,, ,, : 50

(7) Replaceable :

range 200 ,, 100 ,, ; ,, 171 ,, ; —

The water extractable values are generally low and show low averages in all three groups. Centre No. 6 is outstanding for its relatively high value, 17.0 p.p.m. and in this connection it should be pointed out that the area is under grass culture and that the adjoining cultivated area, even where some potash manuring has been carried out, gives a lower value, 12.1 p.p.m. It is also of interest that the trees on area 6 have suffered strongly from potassium deficiency.

The values for the plum areas are distinctly lower than in the other two groups and this applies also to citric soluble and replaceable amounts.

The water soluble values form a very small percentage of the replaceable quantities, averaging only about 2.0 per cent, and reference to the ratio columns in Table II will show that these proportions are even smaller in the subsoil samples.

The average for citric soluble potassium is very similar to the value obtained by Stewart (14) for 12 samples of representative Scottish soils, viz., 86 p.p.m. K_2O against the present values of 84, 58 and 86 p.p.m. K. Here again, the plum values appear abnormally low. Stewart's value for citric soluble as percentage of replaceable for 13 surface soils was 52 per cent ; in the present instance the values are 42, 45 and 50.

The proportion of citric soluble to replaceable does not show very marked tendencies to vary with depth, both decreasing in the subsoil, though in most of the unmanured samples there is a slight rise in the ratio of citric soluble in passing from surface soil to subsoil.

The replaceable values show a wide range, particularly in the case of the apples group, where two very high values, 300 and 360 p.p.m. occur. These two centres are again areas of severe starvation, in fact, in the 360 case at Centre 10 the majority of trees were practically dead at the time of sampling. It is also of interest to note that at this centre, citric soluble potash is relatively low, being much lower on the bad area (b) than on the successful area (a) although the values for the replaceable form are similar. Centre 6, with 300 p.p.m. replaceable also showed the high water soluble figure previously discussed.

Table III has been constructed with the object of showing the effects of various potassic manurial treatments on the contents of the three forms of potassium in the soils.

TABLE II.
Soil Data.

Class of Fruit.	Centre No.	Special Soil and Manurial Features.	Depth of Sample.	Total Nitrogen %	K in Soils p.p.m.				K Ratios.		
					Water Extract 1:1	Sol. in 1% Citric Acid.	Replaceable.	Citric sol.	Water Extract.	Replaceable.	Replaceable.
APPLES.	1 (a)	No potash manures (1924 sample). do. (1931 sample). 10 cwt. K_2SO_4 during period 1926-1930 (1931 sample).	Surface.	—	7.0	108	150	15	21	1.4	1.4
	(b)		do.	—	2.5	105	150	42	60	1.4	1.4
	(b)		do.	0.136	7.5	138	200	14	27	1.5	1.5
	2	No potash manures.	Surface.	—	4.0	55	120	14	30	2.2	2.2
	3	No potash manures.	Surface.	—	2.2	85	160	39	73	1.8	1.8
	4 (a)	Bad area. No potash manures.	Surface.	0.167	2.5	38	120	15	48	3.2	3.2
	(b)	Better area. No potash manures.	do.	—	2.0	54	200	27	100	3.7	3.7
	5 (a)	Bad area. No potash manures.	Surface.	0.305	1.6	55	100	34	70	1.8	1.8
	(b)	Better area. No potash manures.	do.	0.161	2.5	68	200	25	80	2.9	2.9
	6 (a)	Grass. No potash.	Surface.	—	17.0	137	300	8	18	2.2	2.2
	(b)	Grass. 4 cwt. K_2SO_4 in 1928.	Subsoil.	—	2.3	78	140	34	61	1.8	1.8
	(c)	Grass. 30½ cwt. K_2SO_4 in 1923-1931.	Surface.	—	17.0	169	250	10	15	1.5	1.5
	(d)	Arable. 8 cwt. K_2SO_4 in 1928-1931.	Subsoil.	—	3.0	80	120	27	40	1.5	1.5
	(e)	Arable. 30½ cwt. K_2SO_4 in 1923-1931.	Surface.	—	32.0	268	400	8	13	1.5	1.5
	(e)	Arable. 30½ cwt. K_2SO_4 in 1923-1931.	Subsoil.	—	5.6	91	240	16	43	2.6	2.6
	(a)	Grass. 4 cwt. K_2SO_4 in 1928.	Surface.	—	12.1	165	180	14	15	1.1	1.1
	(b)	Better area. No potash manures.	Subsoil.	—	1.1	84	100	30	90	3.0	3.0
	(c)	Grass. 30½ cwt. K_2SO_4 in 1923-1931.	Surface.	—	20.0	255	340	13	17	1.3	1.3
	(d)	Arable. 8 cwt. K_2SO_4 in 1928-1931.	Subsoil.	—	0.8	54	80	17	100	1.5	1.5
	(e)	Arable. 30½ cwt. K_2SO_4 in 1923-1931.	Surface.	—	—	—	—	—	—	—	—
	(e)	Arable. 30½ cwt. K_2SO_4 in 1923-1931.	Subsoil.	—	—	—	—	—	—	—	—

TABLE II (continued).

Class of Fruit.	Centre No.	Special Soil and Manurial Features.	Depth of Sample.	Total Nitrogen %	K in Soils p.p.m.			K Ratios.		
					Water Extract 1:1	Sol. in 1% Citric Acid.	Replaceable.	Citric sol. Water Extract.	Replaceable. Water Extract.	Replaceable. Citric Sol.
APPLES.	7 (a)	No manure since planting. 1 dressing nitrate, 1931, since planting. K_2SO_4 (3 cwts.), 1931, 1 dressing K_2SO_4 (3 cwts.), 1931, since planting. 1 dressing nitrate + K_2SO_4 , 1931, since planting. Manured every year since planting (includes 45 tons dung, 15 cwts. K_2SO_4 and 4 cwts. KCl).	Surface.	0.123	4.5	90	190	20	42	2.1
	(b)		do.	—	6.0	72	195	12	33	2.7
	(c)		do.	—	5.5	74	160	13	30	2.1
	(d)		do.	—	6.0	98	150	16	26	1.5
	(e)		do.	—	15.0	133	250	9	17	1.9
	8 (a)	1½ cwts. per acre nitrate of soda annually since planting in 1912. As above, but 2 cwts. K_2SO_4 annually since 1923. Sulph. Ammonia 1½ cwts., Super. 5 cwts. K_2SO_4 2½ cwts. annually since planting. F.Y.M. at 20 tons per acre annually since planting.	Surface.	0.301	5.0	—	230	—	46	—
	(b)		do.	—	10.0	—	400	—	40	—
	(c)		do.	—	18.0	—	500	—	31	—
	(d)		do.	—	40.0	—	720	—	18	—
	9	Practically no manure since planting and no potash.	Surface. Subsoil.	—	5.0 1.7	128 59	260 160	—	52 94	—
	10 (a)		Surface. Subsoil.	—	4.8 3.2	217 117	340 100(?)	45 37	71 82	1.6
	(b)	Good area of Bramley's (1926). Lane's failure area (1926). do. (1931), after 1 ton K_2SO_4 , period 1927-1931. do. but better trees.	Surface. Subsoil.	0.157	5.8 2.1	82 39	360 170	14 19	42 81	4.4
	(c)		Surface. Subsoil.	—	28.0 21.0	278 300	800 800	10 14	28 38	2.9
	(d)		do.	—	—	—	—	—	—	2.7

TABLE II (continued).

Class of Fruit.	Centre No.	Special Soil and Manurial Features.	Depth of Sample.	Total Nitrogen %	K in Soils p.p.m.			K Ratios.		
					Water Extract 1:1	Sol. in 1% Citric Acid.	Replace-able.	Citric sol. Water Extract.	Replace-able. Water Extract.	Replace-able. Citric Sol.
APPLES.	11	Manure to black currants only.	Surface.	0.146	3.5	94	180	27	30	1.9
PLUMS.	12	No potash manures.	Surface.		1.3	69	100	53	72	1.4
	13	do.	Surface.	0.233	1.6	48	100	29	62	2.0
	14	do.	Surface.	0.109	2.3	60	190	26	83	3.2
	15	do. Heavy nitrogen and phosphate.	Surface.	0.204	2.2	45	160	20	73	3.5
	16 (a)	Good area. Manure to black currants. No potash manures.	Surface.	0.263	9.8	195	388	20	30	1.5
	(b)	Poor area. Manures as above good area.	do.	0.218	—	—	130	—	—	—
	(c)	Originally poor, K ₂ SO ₄ at 4 cwts. per acre, 1929-1930.	do.	—	3.5	—	250	—	71	—
	17	Previous heavy dressings with N, and P, 9 cwts. K ₂ SO ₄ during period 1929-1931.	Surface. Subsoil.	0.207 —	5.0 0.7	115 94	340 130	23 134	68 136	3.0 1.4
	18	Previous heavy dressings of N, and P, 12 cwts. K ₂ SO ₄ , 4 cwts. KCl. during period 1929-1931.	Surface.	0.328	11.0	170	400	15	36	2.3
	19	No potash manures. Newly broken up grassland.	Surface.	0.291	0.6	66	90	110	150	1.4

TABLE II (continued).

Class of Fruit.	Centre No.	Special Soil and Manurial Features.	Depth of Sample.	Total Nitrogen %	K in Soils p.p.m.			K Ratios.		
					Water Extract 1:1	Sol. in 1% Citric Acid.	Replace-able.	Citric sol. Water Extract.	Replace-able. Water Extract.	Replace-able. Citric Sol.
BUSH FRUITS.	20 (a)	Plot 1. Better area. No manure since planting, 1921 (1931 sample).	Surface.	0.230	3.5	77	210	22	60	2.7
	(b)	Plot 9. Severe potash deficiency. No manure since planting, 1921 (1931 sample).	do.	0.202	3.0	53	120	18	40	2.3
	21 (a)	Plot A2. No manure since planting, spring, 1929.	Surface.	—	2.0	47	100	24	50	2.1
	(b)	Plot C2. 4 cwt. NaNO ₃ , 3 cwt. Super., 3 cwt. K ₂ SO ₄ annually, 1929-1931.	Surface.	—	12.8	129	260	10	20	2.0
	22 (a)	Large Experiment. No manure since 1927.	Surface. Subsoil.	0.099	4.6	101	190	22	41	1.9
	(b)	Large Experiment. 1 ton CaCO ₃ , 1927.	Surface. Subsoil.	—	2.5	70	110	28	44	1.6
	(c)	Large Experiment. 4 cwt. K ₂ SO ₄ annually, 1927-1931.	Surface. Subsoil.	—	5.8	86	190	15	33	2.2
	(d)	Small Experiment. No manure since 1927.	Surface. Subsoil.	—	2.8	83	120	30	43	1.4
	(e)	Small Experiment. 4 cwt. K ₂ SO ₄ annually since 1927-1931.	Surface. Subsoil.	0.089	21.0 4.8	147 71	400 220	7 15	19 45	2.7 3.0
23		Small Experiment. 4 cwt. K ₂ SO ₄ annually since 1927-1931.	Surface. Subsoil.	—	2.9	57	200	20	68	3.8
		Fruit no manure. Inter-crop complete fertilizer year of sampling.	Surface. Subsoil.	0.195	4.0	—	240	—	40	—
				—	2.0	183 80	185	91	92	1.0

TABLE III.
Effects of Potash Manures and of Farmyard Manure Dressings on Water Extractable, Citric Soluble and Replaceable Potassium.

Centre No.	Manurial Dressings, etc.	Water Extractable. K. p.p.m.				Soluble in 1% Citric Acid. K. p.p.m.				Replaceable K. p.p.m.			
		Before Manuring.		After Manuring.		Gain or Loss.		Before Manuring.		After Manuring.		Gain or Loss.	
		Sur-face. soil.	Sub-face. soil.	Sur-face. soil.	Sub-face. soil.	Sur-face. soil.	Sub-face. soil.	Sur-face. soil.	Sub-face. soil.	Sur-face. soil.	Sub-face. soil.	Sur-face. soil.	Sub-face. soil.
APPLES.													
1	10 cwt. K ₂ SO ₄ , 1926-1931.	2.5	—	7.5	—	5.0	—	105	—	138	—	150	—
6	4 cwt. K ₂ SO ₄ , 1928. (Grass Culture.)	17.0	2.3	17.0	3.0	0.0	0.7	137	78	169	80	300	140
6	30½ cwt. K ₂ SO ₄ , 1923-1931. (Grass Culture.)	17.0	2.3	32.0	5.6	15.0	3.3	137	78	268	91	300	140
6	122½ cwt. K ₂ SO ₄ , 1923-1931.	12.1	1.1	20.0	0.8	7.9	-0.3	165	34	255	54	180	100
7	3 cwt. K ₂ SO ₄ , 1931.	4.5	—	5.5	—	1.0	—	90	—	74	—	190	—
7	do.	6.0	—	6.0	—	0.0	—	72	—	98	—	195	—
7	Manures include 45 tons F.Y.M., 15 cwt. K ₂ SO ₄ , 4 cwt. KCl, 1919-1931.	4.5	—	15.0	—	10.5	—	90	—	133	—	190	—
8	16 cwt. K ₂ SO ₄ , 1923-1931.	5.0	—	10.0	—	5.0	—	—	—	—	—	230	—
8	Includes 50 cwt. K ₂ SO ₄ , 1912-1931.	5.0	—	16.0	—	11.0	—	—	—	—	—	230	—
8	400 tons F.Y.M., 1912-1931.	5.0	—	40.0	—	35.0	—	—	—	—	—	230	—
10	20 cwt. K ₂ SO ₄ , 1927, 1931.	5.8	—	28.0	—	22.2	—	82	—	278	—	360	—
BUSH FRUITS.													
21	9 cwt. K ₂ SO ₄ , 1929-1931.	2.0	—	12.8	—	10.8	—	47	—	129	—	100	—
22	20 cwt. K ₂ SO ₄ , 1927-1931.	4.6	2.5	21.0	4.8	16.4	2.3	101	70	147	71	190	110
22	do.	2.9	—	4.0	—	1.1	—	—	—	—	—	200	—

* This quantity is a difference figure between amounts applied to 2 plots, viz. 30½ cwt. and 8 cwt. K₂SO₄.
† The figures in brackets denote percentages of added potassium present in replaceable form in 1931.

The data relate to eleven apple areas and three with bush fruits ; unfortunately, data are not available for any of the plum plots and only 4 subsoils could be studied.

It will be seen from the list of manurial treatments that some typical effects of long period experimental dressings can be ascertained, as at Centres 6, 7 and 8, whilst the effects of heavy dressings for shorter periods, Centres 1, 10, 21 and 22, and of single applications during the life of a plantation, Centres 6 and 7, can also be determined.

In the last two columns of data for each form of potassium, gains or losses recorded in particular comparable instances are given, whilst in the case of these columns under replaceable potassium, where gains are recorded, the excess amounts of potassium present over the unmanured plot are shown (value in brackets) as percentages of the actual amounts of potassium applied. These values enable us to see the proportions of applied potassium which have been retained by the soils in the replaceable form.

In considering the results in this table, it must be remembered that trees and bushes are actually growing on the plots and that, in all cases with the exception of Centre 10, significant, and—excepting Centres 6 (4 cwt. K_2SO_4), 7 (3 cwt. K_2SO_4)—very marked responses to the potash manuring have resulted. These responses have been accompanied by greatly increased intakes of potassium, as determined by data secured for increased growth, cropping and chemical composition of shoot and fruit portions, the last feature being illustrated in Table IV.

With the exception of four cases in which less potassium was found on the manured areas than on the comparable unmanured sections, the manurial treatments have been followed by increases, often very considerable, in all three forms of potassium.

Of the cases where losses were recorded, in three of these, only single dressings of potassium sulphate had been applied over a long period of years but, in the other, relatively heavy dressings had been given. In the latter case, however, it should be noted that the losses are relatively small and confined to the subsoil, the surface soil values showing significant increases.

In all four cases, it is also probable that the losses recorded are due in part to initial irregularities in the distribution of potassium over the respective areas. Tree growth on the plots, prior to potash treatment, was very irregular in all cases and, at Centre 6, the potash treated sections were specially selected for treatment because of showing more drastic starvation symptoms than the area subsequently left unmanured.

It is of interest to note the large increases in water soluble potassium which have resulted in the surface soils from the heavy manurial dressings, being especially notable in the long period experiment at Centre 8. One plot at Centre

22 is a notable exception and no reason for the low values can be given. The bushes on the manured plot have responded markedly to the potash treatment.

The gains recorded for replaceable potassium require particular mention and the values in brackets are of special interest. These latter show that in the majority of cases where heavy potassic dressings have been applied, considerable proportions of the potassium are still apparently present in the surface soil in the replaceable form and should therefore presumably be available to roots in that horizon. If, however, the trees are in some cases mainly dependent on available supplies of the element in the subsoil, then these supplies of added potassium will not yet be within reach of the absorbing roots. The case at Centre 10 is especially interesting for practically the whole of the added potassium appears to be present in the surface soil. The trees on this area, prior to potash treatment, were practically dead and, up to 1931, when the soil sample was taken, they had not made any appreciable growth, although they had the appearance of beginning to recover.

It will be seen from Table IV—area 10(c)—that, in 1931, analysis of the leaves indicated that the trees were still potash starved.

Data on Plant Material.

The chemical data on the plant material are presented in Table IV. They refer only to the potassium contents of particular portions of the plants and are expressed throughout as percentages of the element in dry matter. As stated previously, they are merely selections from a large bulk of available data and serve to illustrate the potash starved conditions of the trees on unmanured areas and the effects of manuring with potassic manures in raising the potassium contents of the plants.

In considering the results it should be noted that the largest differences will usually be shown in the leaves and the smallest in the fruits.

For some centres results are given for several seasons and in such cases these have been obtained, in conjunction with field records, in following the effects of the manurial treatments year by year in attempts to ascertain the time required to produce significant reactions. Typical cases of this procedure are provided by Centres 16, 17, 18; at Centre 16 a marked effect was apparent in 1930, after two years of treatment, at Centre 17 in 1931 after 3 years, and at Centre 18 in 1930 after two years.

DISCUSSION.

When the results in Tables II and IV are considered together it is seen that the potassium values for the soils on the various plots are related to those for the plant materials in the respective cases.

On unmanured areas the potash contents of the plants are low and show that the trees and bushes are suffering from starvation of the element.

TABLE IV.
Data on Plant Material.

Class of Fruit, Varieties, etc.	Centre No.	Special Features.	Season of taking analytical sample.	Portion of Plant Analysed.					Fruit Pulp.
				Terminal Shoot Portions.					
				Leaves. K ₂ O in D.M. %	Bark. K ₂ O in D.M. %	Wood. K ₂ O in D.M. %	Bark + Wood. K ₂ O in D.M. %		
APPLES.									K ₂ O in D.M. %
Worcester Pearmain.	1 (a)	No potash manures.	1927-1930	—	—	—	—	—	$\begin{cases} 0.82 \\ 0.65 \\ 0.56 \end{cases}$
	(b)	10 cwt. K ₂ SO ₄ during period 1926-1930.	1927-1930	—	—	—	—	—	$\begin{cases} 0.71 \\ 0.88 \\ 0.83 \\ 0.82 \\ 0.82 \end{cases}$
Early Victoria.	4 (a)	Bad area. No potash manures.	1930	—	—	—	—	—	0.75
	(b)	Better area. do.	1930	—	—	—	—	—	0.93
Lane's Prince Albert.	5 (a)	Bad area. No potash manures.	1929	0.42	—	—	—	—	—
		Better area. do.	1929	1.94	—	—	—	—	—
Allington Pippin.	6 (a)	Grass from 1929. No potash. Do. K ₂ SO ₄ annually from 1923.	1929	0.39	—	—	0.36	—	—
	(c)	Grass from 1929. 4 cwt. K ₂ SO ₄ in 1928.	1929	1.42	—	—	0.49	—	$\begin{cases} 0.59^* \\ 0.60^* \\ 0.96^* \end{cases}$
Grenadier.	(b)	As (a) above.	1931	—	—	—	—	—	$\begin{cases} 0.60^* \\ 0.96^* \\ 0.88^* \end{cases}$
	(c)	As (c) above.	1931	—	—	—	—	—	$\begin{cases} 0.60^* \\ 0.96^* \\ 0.88^* \end{cases}$
Worcester Pearmain on Malling No. 1 Rootstock.	7 (a)	No manure since planting. Manured annually since planting.	1930	0.702	0.501	0.249	—	—	—
	(e)	As (a) above (size grades 5 and 6).	1930	1.260	0.704	0.345	—	—	$\begin{cases} 0.44 \\ 0.43 \\ 1.12 \\ 0.78 \\ 0.74 \end{cases}$
	(a)	As (e) above (size grades 2 to 5).	1929	—	—	—	—	—	$\begin{cases} 0.74 \\ 0.63 \end{cases}$
	(e)		1929	—	—	—	—	—	$\begin{cases} 0.74 \\ 0.63 \end{cases}$

* Fruits from Spur pruned trees.

† Fruits from Regulated pruned trees.

TABLE IV (continued).

Class of Fruit, Varieties, etc.	Centre No.	Special Features.	Season of taking analytical sample.	Portion of Plant Analysed.				
				Terminal Shoot Portions.				Fruit Pulp.
				Leaves. K ₂ O in D.M. %	Bark. K ₂ O in D.M. %	Wood. K ₂ O in D.M. %	Bark + Wood. K ₂ O in D.M. %	
APPLES. Grenadier.	8 (a)	1½ cwts. p.a. NaNO ₃ annually since 1912. No potash.	1927 (shoots)	0.63	0.67	0.32	—	{ 0.44
	(b)	As (a) but 2 cwts. K ₂ SO ₄ annually since 1923.	1928, 1929 (fruits)	0.98	—	—	—	{ 0.65
	(c)	Sulph. Ammonia 1½ cwts., Super. 5 cwts., K ₂ SO ₄ 2½ cwts. p.a. since planting.	1927 (shoots)	1.54	0.96	0.43	—	{ 0.90
	(d)	*F. Y. M. at 20 tons p.a. annually since planting.	1928, 1929 (fruits)	—	—	—	—	{ 0.77
Lane's Prince Albert.	10 (c)	Failure area 1926. 1 ton K ₂ SO ₄ period 1927-1931.	1927 (shoots)	1.98	1.20	0.48	—	{ 1.18
	(d)	Response very small. Do., but trees originally better than (c) and excellent response.	1931	0.82	—	—	—	{ 0.90
			1931	1.21	—	—	—	—
Plums. Purple Pershore.	13 (a)	No potash manures.	1929 Leaves	0.41	—	—	—	0.96
	(b)	Failure Trees.	1930 Fruits	1.76	—	—	—	1.41
Purple Pershore.	14 (a)	No potash manures.	1930	—	—	—	—	0.86
	(b)	Failure Trees.		—	—	—	—	1.22
	(c)	Better Trees.		—	—	—	—	—
Purple Pershore.	15 (a)	No potash manures.	1928	0.26	—	—	—	1.08
	(b)	Heavy N. and P.		2.11	—	—	—	1.73
	(c)	Failure Trees.	1930	—	—	—	—	1.03
	(d)	Better Trees.		—	—	—	—	1.40
	(e)	Originally Failure Trees sprayed with 1% K ₂ SO ₄ .	1931	2.24	—	—	—	1.29
	(f)	As above.		2.07	—	—	—	—

TABLE IV (continued).

Class of Fruit, Varieties, etc.	Centre No.	Special Features.	Season of taking analytical sample.	Portion of Plant Analysed.					Fruit Pulp.	
				Terminal Shoot Portions.				Bark + Wood. K ₂ O in D.M. %		K ₂ O in D.M. %
				Leaves. K ₂ O in D.M. %	Bark. K ₂ O in D.M. %	Wood. K ₂ O in D.M. %	Wood. K ₂ O in D.M. %			
Plums. Purple Pershore.	16	Trees poor previous to 1929. K ₂ SO ₄ at 4 cwts. p.a., 1929-1930. Poorest Trees. Best Trees. As (a) above. As (b) above. As (a) above. As (b) above. As (a) above. As (b) above.	1928	1.09 1.83 1.17 1.92 1.87 1.61 1.27 1.64	— — — — — — — —	— — — — — — — —	— — — — — — — —	— — — — — — — —	K ₂ O in D.M. %	
			1929							
			1930							
			1931							
			1932							
Purple Pershore.	17	Previous heavy dressings of N. and P. 9 cwts. K ₂ SO ₄ , period 1929-1931. Poorest Trees. Best Trees. As (a) above. As (b) above. Sprayed with 1% K ₂ SO ₄ (originally poorest trees on plot). As (a) above. As (b) above. As (c) above. As (a) above. As (b) above. As (c) above.	1928	0.54 2.04 0.55 2.26	— — — —	— — — —	— — — —	— — — —	1.03 1.40 1.04 1.25	
			1929							
			1930							
			1931							
			1932							
			1933							
			1934							
			1935							
			1936							
			1937							
			1938							

TABLE IV (continued).

Class of Fruit, Varieties, etc.	Centre No.	Special Features.	Season of taking analytical sample.	Portion of Plant Analysed.				
				Leaves. K ₂ O in D.M. %	Bark. K ₂ O in D.M. %	Wood. K ₂ O in D.M. %	Bark + Wood. K ₂ O in D.M. %	Fruit Pulp. K ₂ O in D.M. %
PLUMS. Purple Pershore.	18	Previous heavy dressings of N. and P. 12 cwt. K ₂ SO ₄ , 4 cwt. KCl., period 1929-1931.						
	(a)	Typical trees of plot (failures 1928).	1928	0.40	—	—	—	1.09
	(b)	Green trees on adjoining soil area (strong growth 1928).						
	(a) above.	As (a) above.	1929	2.41	—	—	—	1.23
	(a) above.	As (a) above.	1930	0.48	—	—	—	—
Purple Pershore.	(a) above.	As (a) above.	1931	1.64	—	—	—	—
	(b)	As (b) above.		3.69	—	—	—	—
	19	No potash manures. Newly broken up grassland.	1931	0.30	—	—	—	—
Bush FRUITS. Gooseberries. var. Keepsake.	20 (a)	Plot 1. Better area. No manure since planting 1921.						
	(b)	Plot 9. Severe potash deficiency. Manurial as (a).	1927	1.06	—	—	0.57	1.45
	(c)	Plot 12. N.P.K. treatment annually since 1921 (100 lbs. K ₂ O annually). Strong potash effect.		0.88	—	—	0.61	1.24
	(a) above.	As (a) above.		1.77	—	—	1.27	1.61
	(b) above.	As (b) above.	1928	1.12	—	—	—	1.18
Purple Pershore.	(d)	Plot 4. Treatment etc. as Plot 12 above.		0.73	—	—	—	1.08
				2.54	—	—	—	1.73

TABLE IV (continued).

Class of Fruit, Varieties, etc.	Centre No.	Special Features.	Season of taking analytical sample.	Portion of Plant Analysed.					Fruit Pulp.
				Terminal Shoot Portions.				Bark + Wood. K ₂ O in D.M. %	
				Leaves. K ₂ O in D. M. %	Bark. K ₂ O in D. M. %	Wood. K ₂ O in D. M. %			
BUSH FRUITS. Gooseberries. var. Careless.	22 (a)	Large expt. No manure since 1927. Severe potassium starvation.	1929	0.57	—	—	0.61	—	—
	(c)	Large expt. 4 cwts. K ₂ SO ₄ annually 1927-1931. Good growth.		3.58	—	—	1.71	—	—
	(d)	Small expt. Treatment etc. as (a). More severe starvation.	1929	0.35	—	—	0.44	—	—
	(e)	Small expt. Treatment etc. as (c).		2.32	—	—	1.27	—	—
	(d) (e)	As (d) above. As (e) above.	1931	0.70	—	—	0.37	—	—
		2.12		—	—	1.57	—	—	
Red Currants and Gooseberries.	23 (a)	Red Currants. No manure to fruit.	1928	0.87	—	—	0.53	—	—
	(b)	Red Currants. K ₂ SO ₄ at 4 cwts. p.a. 1927, 1928. Only poor response to potash.		2.04	—	—	0.79	—	—
	(c)	Gooseberries as (a).		0.48	—	—	0.33	—	—
	(d)	Do. as (b). Strong response to potash.		2.33	—	—	1.36	—	—

It is thus possible to consider the values for the different forms of soil potassium in these cases and to see whether starvation effects occur under conditions of relatively low or high supplies of the element.

In all cases the values for water extractable potassium, with the possible exception of 17 p.p.m. at Centre 6, would be regarded as low, the values for the plum centres being exceptionally so.

The results for citric soluble and replaceable potassium may be considered together since the average value for the former appears to comprise a fairly normal percentage of the average for the latter, and hence conclusions which are applicable to the latter may be considered to hold for the former.

Neubauer, from results with his seedling test, has formulated a list of minimum values for various crops and if quantities of potash below these are obtained in the seedlings it is considered that potash manuring is necessary. It is also claimed that advice based on these values has given about 85 per cent of correct results. Some Neubauer values, as K_2O , for various plants are as follows: rye and wheat, 14 mgms. ; barley and oats, 18 mgms. ; red clover, 29 mgms. ; alfalfa, 34 mgms. ; potatoes, 37 mgms. ; sugar beet, 39 mgms. These values can be expressed in terms of soil potassium, as K_2O , as under: rye and wheat, 140 p.p.m. ; barley and oats, 180 p.p.m. ; red clover, 290 p.p.m. ; alfalfa, 340 p.p.m. ; potatoes, 370 p.p.m. ; sugar beet, 390 p.p.m.

It has been generally found in comparing Neubauer values with exchangeable results that the former are rather smaller than the latter and the value obtained by Stewart (14) in a study of this kind, viz. 74 per cent, may be taken as typical.

Since in the present paper results are expressed in terms of the element and not the oxide, the Neubauer values as K_2O may be considered as roughly comparable with our exchangeable values as K_2 (actual ratio $\frac{K_2}{K_2O} = 0.83$). When this is done it is seen that only at two centres do the values rise above the minimum set for red clover, whose requirements are of medium character, and thus it may be said that the supplies of replaceable and citric soluble forms of the element are distinctly low as judged by the standards of agricultural crops. In this connection it may be recalled that the requirements of fruit plants in this country are possibly higher than most agricultural crops since failures of the former are common where the latter are successful. The maximum values obtained for exchangeable potassium for apples, 300 and 360 p.p.m., should be noted. In the cases of the other fruits none of the values approach these.*

* It is of interest in connection with the present results that Lilleland, in California, has found Neubauer values for soil potassium to show closer agreement with the field behaviour of prune trees than do values for replaceable potassium, particularly in certain soils low in replaceable K which do not produce prune die-back. (Private communication to E.L.P.)

The main points of interest in connection with the effects produced on the soil potassium by the manurial treatments are that heavy dressings of both potassic manures and of farmyard manures have raised the values for the different forms in the surface soils by appreciable extents, and that large percentages of the dressings applied have been retained in the surface soils in the base exchange complex. The significance of this observation has been previously discussed.

CONCLUSIONS.

The amounts of potassium present as water extractable, citric soluble and replaceable forms in the surface soils of some areas on which various fruit plants have exhibited marked symptoms of potassium deficiency were found to be low as judged by standards set for agricultural plants.

The deficiencies were clearly reflected in the potassium contents of terminal shoot portions and of the pulp of the fruits.

Heavy dressings of potassic manures and of farmyard manure which were effective in overcoming the deficiency effects considerably raised the quantities of the three forms of potassium in the surface soils and also caused significant increases in the potassium contents of the plants.

Where heavy dressings of potassic manures and of farmyard manure had been applied annually for considerable periods, large percentages of the added potassium were present in the respective surface soils in the exchangeable form.

SUMMARY.

The potassium status of the soils and fruit plants in some well marked and proved cases of potassium starvation of apples, plums and bush fruits were examined.

In the soil studies, determinations were made on surface soil samples (and a few subsoils) of water extractable 1:1, citric soluble (Dyer's method) and replaceable potassium. The soil samples were representative of unmanured potash deficient areas, and areas to which heavy dressings of potassic manures and of farmyard manures had been given and had effectively corrected the starvation effects.

The results obtained on the samples from the unmanured plots showed low amounts of the various forms of potassium whilst those for the manured samples reflected the treatments for all forms of the element.

It was found that large percentages of the potassium applied to the plots were usually present in the surface soils in the exchangeable form.

The deficiency effects were clearly shown by the plant analyses, and the potassium contents of the plant parts—terminal shoots and fruit pulp—were significantly raised by the manurial treatments.

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GAS STORAGE OF FRUIT. III. LANE'S PRINCE ALBERT APPLES

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INTRODUCTION.

IN the previous paper in this series* an account was given of the results of storage trials carried out at the Low Temperature Research Station, Cambridge, to ascertain the most satisfactory combination of the three variables, (1) temperature, (2) concentration of carbon dioxide, and (3) concentration of oxygen for the storage of Bramley's Seedling apples. It was found that the most efficient combination of the conditions tested was a temperature of 5° C. (41° F.) with an atmosphere containing about 10 per cent carbon dioxide and the equivalent subnormal percentage of oxygen. With this combination of controlled conditions the results obtained as regards commercial storage life† were more than one and a half times better than the best possible by the use of controlled temperature alone (i.e. cold storage in air).

The optimum conditions for Bramley's, which can be obtained by the simple method of restricted and controlled ventilation with refrigeration, have during the past few years been used on a commercial scale with considerable success, and growers are now anxious to extend this method to other varieties of apples. Hence there is now a pressing need for information as to the optimum conditions for the gas-storage of other varieties.

Since there was no *a priori* reason for assuming that the best conditions for Bramley's would also be the best for other varieties, and since on theoretical grounds it might be expected that conditions where the proportions of both oxygen and carbon dioxide are low would be more efficient in retarding ripening than those obtainable by the method of restricted and controlled ventilation,‡ it was decided to carry out during the season 1931-32 a comprehensive experiment with the following four varieties of apples namely, Lane's Prince Albert, Annie Elizabeth, Ellison's Orange and Cox's Orange Pippin. For these experiments the special facilities provided at the Ditton Laboratory were used.

* F. Kidd and C. West. Gas Storage of Fruit. II. *Journ. Pomol. and Hort. Sci.*, VIII, No. 1, 1930, p. 67.

† Commercial storage life is defined as the interval of time between the storage date of the fruit and the development of 10 per cent wastage in the store.

‡ F. Kidd, C. West and M. N. Kidd. Gas Storage of Fruit. Special Report No. 30, Food Investigation Board, London, 1927.

It is now well known that when certain critical limits of CO_2 -concentration and oxygen-concentration are exceeded even for quite a short period, wholesale damage to the fruit may result.* Such damage has frequently occurred in the overseas transport of apples. Accordingly, these experiments were planned to provide some more definite knowledge regarding safe limits of oxygen and carbon dioxide at different temperatures.

THE VARIETIES TESTED.

The varieties tested were Lane's Prince Albert (off Plot 11 at the East Malling Research Station), † Annie Elizabeth (from Exning, near Cambridge), Ellison's Orange (half sample from Wisbech and half sample from Cottenham), and Cox's Orange Pippin (from Chelmsford). All the varieties were gathered on the same day (21/9/31) and were transported by road to the Ditton Laboratory where they were carefully graded, sampled and wrapped in oiled wrappers preparatory to storage.

GRADING AND SAMPLING.

It is clearly of critical importance that the samples should be as nearly similar at the outset as possible. Great care was therefore taken in the operation of sampling.

In the first place the fruit to be used is divided into classes according to known differences in pre-storage history, e.g., date of gathering, stock, soil, age of tree. Each of these classes is separately graded for size, all imperfect fruits being removed. Each sample then receives an equal number of fruits from each grade of each class.

THE STORAGE CONDITIONS.

The following storage conditions were selected: three temperatures, namely, 1°C . (34°F .), 4°C . (39°F .) and 10°C . (50°F .), and at each of these temperatures ten different atmospheres, namely,

Gas Series 1-3: 5% carbon dioxide with 2.5%, 5% and 10% oxygen.

Gas Series 4-6: 10% " " " " "

Gas Series 7-9: 15% " " " " "

Gas Series 10: no carbon dioxide with 21% oxygen (i.e. air mixture).

In each case the remaining percentage was made up of nitrogen.

In all, therefore, the effects of thirty different storage conditions were compared on samples of apples as nearly as possible comparable when put into store.

* See Special Reports Nos. 12, 20, 22 and 23 of the Food Investigation Board.

† The Lane's Prince Albert apples were off twelve-year-old trees on East Malling rootstocks (types I, III, IV, V, VII, VIII, X and XI) grown on cultivated ground which had received 2 cwt. of potassium sulphate per acre on January 15th. The trees were pruned annually, leader-tipped and long-spurred.

THE CONSTANT-TEMPERATURE ROOMS.

These were cooled by forced air circulation between a central vertical trunk and the walls of the room. Details of the installation are shown diagrammatically in Fig. 1. This method of cooling proved most successful in overcoming those slight differences of temperature in different parts of the room which occurred in the earlier experiments at Cambridge. Throughout the storage period, with the exception of the periods when the fruit was being removed for examination, the temperature in these rooms was uniform both in time and space to about 0.1° F.

THE STORAGE CABINETS.

Thirty cabinets, constructed of sheet iron with welded joints were designed especially for these experiments. Each cabinet has a volume of 16 cu. ft. and is fitted with a "Plymax"* door, held in position by lengths of channel-sectioned steel. A perfectly gas-tight joint is made by a pneumatic tube fitting in a groove between the door and cabinet. Ten cabinets were placed in each of the three constant-temperature chambers. Each cabinet held 18 trays, in two tiers of 9. There were 50 apples per tray.

The method used at the Low Temperature Research Station, Cambridge, of supplying each gas-mixture from a separate gasometer, was abandoned in favour of storing only the three component gases, namely, oxygen, nitrogen and carbon dioxide in separate gasometers under a small positive pressure. The three gases are separately metered and mixed in the desired proportions before delivery to the storage cabinets. This arrangement gives increased accuracy and flexibility, since regulation of the composition of any gas-mixture can be made rapidly and with precision.

After passing through a drier each gas flows into mixing headers through flowmeters of simple design,† with a needle valve to control the rate of flow. These flowmeters are of the capillary-tube type in which rates of flow are recorded as differences in pressure between the ends. An inclined manometer, built integrally with the glass capillary tube, records the drop in pressure.

Each gas-mixture is distributed between three cabinets, one at each temperature. Taps on the inlet are provided to regulate the distribution, vane-meters of special design‡ being used in setting these taps. The flow of gas is set to the minimum which will ensure that no more than a negligible accumulation of carbon dioxide shall occur.‡ From the opposite side of each storage

* "Plymax" = three-ply boards covered with thin galvanized metal sheeting.

† The capillary-tube- and vane-flowmeters used in these experiments are illustrated in Figs. 119 and 120 of the Annual Report of the F.I.B., London, for the year 1931.

‡ Approximately 10 cubic feet per day per cabinet at the lowest temperature and 40 cubic feet per day at the highest temperature.

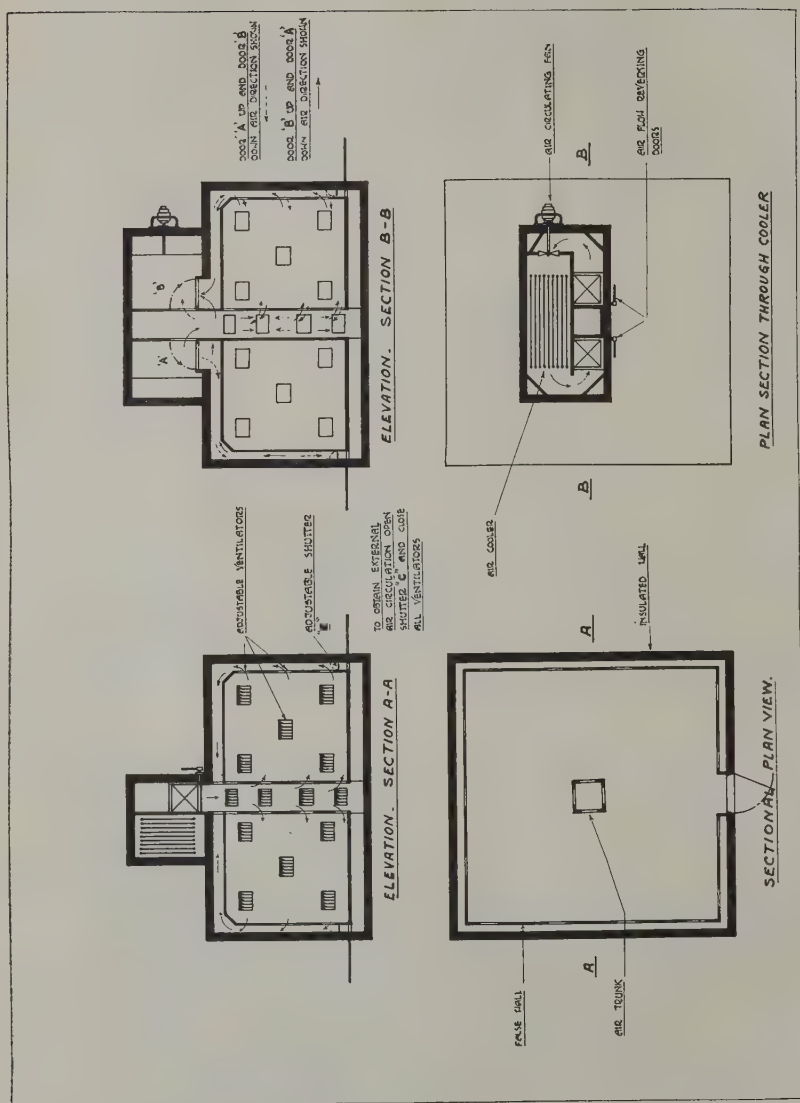


Fig. 1.
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cabinet the gas-mixtures are led away to the outside of the constant-temperature rooms.

The gas-mixtures, before entering the cabinets, pass through towers containing glass beads moistened with a calcium chloride solution of known concentration, and thus enter the cabinets at a definite relative humidity, namely 92 to 94 per cent saturation. Humidity tests on the atmospheres leaving the cabinets show that very little change occurs during the passage of the gases through the chambers.

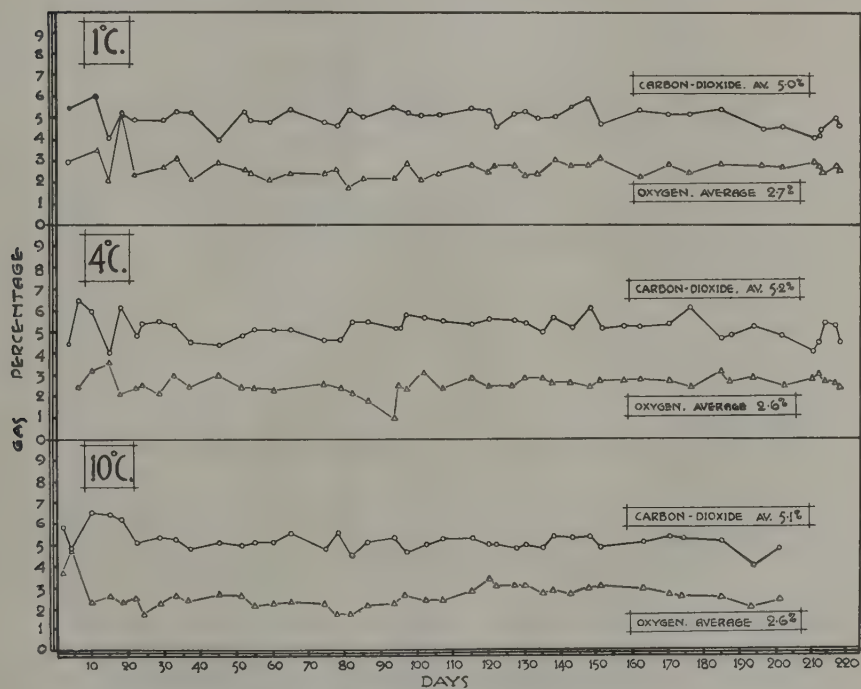


FIG. 2.

The thirty storage cabinets were closed and the atmospheric conditions established on September 28th, 1931, that is, six days after the fruit was gathered. The concentrations of O_2 and of CO_2 in the storage cabinets were checked by frequent analyses* of the gas-mixtures at the outlet. Three typical gas-records (Gas Series 1) are shown in Fig. 2. The average atmospheric conditions in the thirty cabinets for the whole period of storage are given in Table I.

* By means of a Haldane gas analysis apparatus.

In two instances during the first few weeks of storage a breakdown occurred, involving the blocking of the delivery tubes to the cabinets. In both cases the breakdown led to a rise in the concentration of CO₂ from 10 per cent to a value exceeding 15 per cent for a day or two. The results of this temporary exposure of the fruit to the higher CO₂-concentration were, as will be seen below, interesting and of practical significance.

The cabinets were opened and one or more samples of each variety withdrawn and examined for wastage, colour change, flavour and general condition

TABLE I.

Showing average gas-concentrations during experiments.

Gas Series.	Required concentrations.		Actual concentrations.					
			1° C.		4° C.		10° C.	
	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂
1	2.5	5	2.7	5.0	2.6	5.2	2.6	5.1
4	2.5	10	2.8	10.2	2.8	10.3	2.6	10.4
7	2.5	15	2.4	14.8	2.4	15.0	2.5	15.1
2	5	5	5.5	5.0	5.6	5.0	5.4	5.1
5	5	10	5.5	10.0	5.3	10.2	5.5	10.0
*8	5	15	5.2	14.5	5.3	14.8	5.2	14.7
3	10	5	10.1	4.8	9.8	5.0	9.9	5.0
*6	10	10	10.1	9.9	10.3	10.0	10.5	10.1
9	10	15	10.0	14.9	9.7	14.7	10.0	14.8
10	21	0	20.5	0.7	20.1	0.9	20.4	0.9
6a	10	10	—	—	10.9	9.0	—	—

* These atmospheres are obtainable by the normal commercial method of restricted and controlled ventilation.

at intervals of approximately one month, the actual dates being November 4th and December 3rd, 1931, and January 13th, March 1st, April 21st and June 20th, 1932. The time taken to open a cabinet, remove the samples of fruit and close it again was about ten minutes, but several hours elapsed before the atmospheric conditions were re-established.

In the case of one variety (Lane's Prince Albert) at one temperature (39° F.) duplicate samples were stored for chemical analysis, one sample being withdrawn at each examination. Immediately after withdrawal the chemical samples were frozen hard.

From what has been said above it will be evident that one of the conditions common to all the experiments was the avoidance of stagnation and the partial

removal of the volatile products of the fruit by the slow flow of the artificial atmospheres through the storage chambers. In this respect, therefore, the storage conditions differ from those obtained by the method of restricted and controlled ventilation. It seemed desirable to ascertain whether the difference in method affected the stored fruit. To check this point a spare cabinet was utilized, samples of Annie Elizabeth and Ellison's Orange, strictly comparable to those used in the main experiment, being stored at 39° F. under the method of restricted ventilation, giving an average atmospheric composition of 10.9% O₂ and 9% CO₂ (Gas Series 6a) until the experiment was terminated.

CRITERIA AS TO CONDITION OF FRUIT.

The following observations were made at each examination :

- (1) Ground colour, using Ridgway's colour standard.*
- (2) Firmness of flesh (measured by a penetrometer).†
- (3) Surface blemish (superficial scald), estimated as (a) prevalence, i.e., percentage of individual fruits affected, and as (b) intensity, i.e., percentage of surface of the affected fruits scalded.
- (4) Browning of flesh-tissues ; (a) brown heart type, (b) breakdown type, and (c) core-flush type. These are estimated as prevalence and as intensity. Intensity is measured as the percentage of the flesh showing browning in a median transverse section of the fruit. In Tables II, IV and VI data for wastage from breakdown and scald are also presented as total amounts (=prevalence × intensity, expressed as percentage).
- (5) Fungal rotting, expressed as prevalence only. An apple was assessed as rotting as soon as an active rot could be seen, even if only a quarter of an inch in diameter.
- (6) Flavour, aroma and cooking quality. After storage for long periods apples may appear quite sound as judged by any of the above criteria, but may have lost all their characteristic flavour and consistency. In such a condition they are described as being overripe, a stage which, within the limits of the personal equation, can be precisely defined and which definitely marks the limit of storage life.
- (7) Wilting. Under the conditions of these experiments no wilting occurred even after the longest period of storage tested.

* R. Ridgway. Colour Standards and Colour Nomenclature. Washington, D.C., 1912.

† The type of instrument used in these tests is illustrated and described in Department Circular No. 350 of the U.S. Department of Agriculture, Washington, Sept., 1925.

TABLE II.
LANE'S PRINCE ALBERT.

Low-temperature breakdown at 1° C. (34° F.).															Superficial scald at 1° C. (34° F.).				
Gas Series.	O ₂ %	CO ₂ %	4/11/31. 37 days.		3/12/31. 66 days.		13/1/32. 107 days.		1/3/32. 155 days.		22/4/32. 206 days.		20/6/32. 266 days.		Prevalence. Total amount.	Intensity.			
			Preva- lence.	Inten- sity.	Preva- lence.	Inten- sity.	Preva- lence.	Inten- sity.	Preva- lence.	Inten- sity.	Preva- lence.	Inten- sity.	Preva- lence.	Inten- sity.					
			Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.	Total amount.					
1	2.5	5	0	0	0	0	0	0	40	10	26	4	2	40	16	100	0	0	
2	5	5	0	0	0	0	0	0	24	5	20	8	2	20	—	—	0	0	
3	10	5	0	0	0	0	0	0	16	3	20	12	5	40	0	0	0	0	
4	2.5	10	9	30	4	1	13	3	90	31	35	90	36	40	82	100	50	10	20
5	5	10*	96	35	94	43	100	61	100	60	60	100	100	100	—	—	96	33	34
6	10	10	0	0	0	0	4	1	62	13	21	13	5	40	70	100	33	5	14
7	2.5	15	100	29	86	57	96	75	98	37	88	100	100	100	—	—	83	41	49
8	5	15	30	12	33	18	42	29	100	60	60	100	100	100	—	—	88	22	25
9	10	15	46	18	38	18	30	18	100	40	40	100	100	100	—	—	92	26	28
10	21		0	0	0	0	0	0	0	0	0	4	2	60	0	0	0	0	0

* The concentration of CO₂ rose to 16.5% for 2 or 3 days during first period.

Note 1.—Fungal rotting, which is not included in this Table, was significant only in the case of the controls in air, and in these only at the final examination (after 266 days).

Note 2.—In Tables II, IV and VI the figures for each examination are based on a single sample. There is bound to be inherent differences between samples however carefully they are prepared. It is therefore necessary to consider the results as a whole rather than individually.

STORAGE RESULTS.

LANE'S PRINCE ALBERT.

Storage at 1° C. (34° F.).

In comparison with air at the same temperature, all the artificial atmospheres delayed the change in ground colour from green to yellow and retarded the softening of the flesh.

At the first examination, after 37 days' storage, it was already evident that several of the storage conditions tested at 34° F. had caused functional breakdown of various degrees of severity.* At this stage it was also quite clear that the injurious effects of certain artificial atmospheres were far more pronounced at 34° F. than at the two higher temperatures. At 34° F. all the atmospheres containing 10% or 15% carbon dioxide (Gas Series 4 to 9 inclusive) could be ruled out at this early date as being unsuitable for the storage of the Lane's Prince Albert variety (Table II). The wastage was of two types, superficial scald and low-temperature breakdown.†

In sharp contrast to the effects obtained in atmospheres containing 10% or 15% CO₂, neither breakdown nor scald occurred in the atmospheres containing 5% CO₂ until the third examination on January 13th, that is, after 107 days' storage, and even after 206 days' storage it had developed only to a very slight extent. More damage occurred with 5% CO₂ than with air. The amount of oxygen present (2.5%, 5% or 10%) appeared to have but little effect on the occurrence of breakdown or scald.

The commercial storage life at 34° F. of the fruit in all the gas-mixtures tested is given in Table III. It will be seen from this table that the apples

TABLE III.

Lane's Prince Albert Apples at 1° C. (34° F.).

Gas Series.	Oxygen %	Carbon dioxide %	Commercial storage life (in weeks).	Efficiency of gas mixtures. Air = 1.0.
1	2.5	5	16	0.6
2	5	5	15	0.6
3	10	5	15	0.4
4	2.5	10	4	0.1
5	5	10	4	0.1
6	10	10	4	0.1
7	2.5	15	4	0.1
8	5	15	4	0.1
9	10	15	4	0.1
10	21	0	27	1.0

* It was during this period that the serious breakdown occurred in the ventilating system of Gas Series 5 at 34°F., allowing the concentration of CO₂ to reach 16.5 per cent for a couple of days.

† No breakdown of the brown heart type occurred in the Lane's Prince Albert apples.

stored in air had a commercial storage life of twenty-seven weeks ; those stored in 5% CO_2 a life of fifteen weeks, irrespective of the concentration of oxygen ; and those stored in higher concentrations of carbon dioxide a life of less than four weeks, the wastage in every case being due to low-temperature breakdown and scald. At this temperature, therefore, air gave the best result.

Before passing on to a consideration of results obtained at other temperatures it is interesting to analyse a little more carefully the data presented in Table II. Two classes of injury can be distinguished ; (1) that which develops

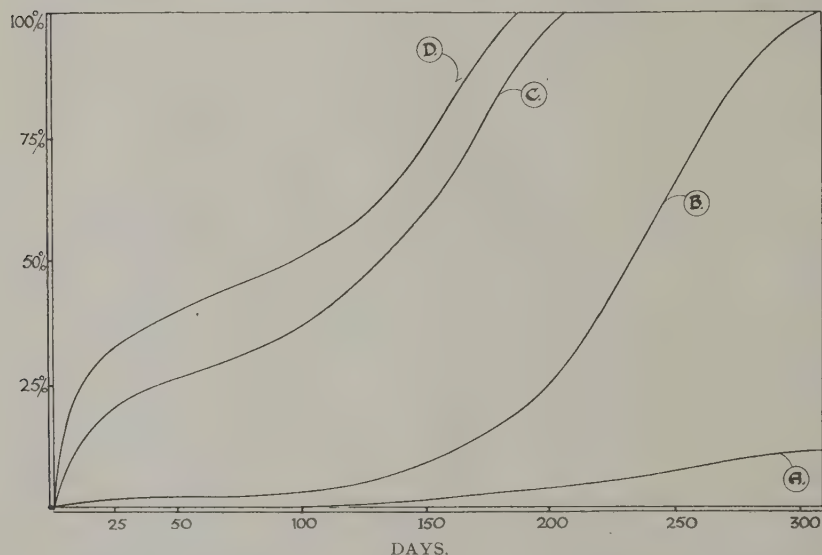


FIG. 3.

Curves A, B and C show respectively the course of development of breakdown at 34°F. in atmospheres containing 5%, 10% and 15% carbon dioxide. The course of development of breakdown in the exceptional case of Gas Series 5 at 34°F. is shown by Curve D.

immediately, or in a very short time after storage (this includes scald and low-temperature breakdown), and (2) that which develops only slowly after long periods of storage. The latter class of injury consists mainly of breakdown, the amount of scald being negligible. With 10% CO_2 there was immediate damage from scald, but very little immediate damage from breakdown. The course of development of breakdown in 5%, 10% and 15% CO_2 is shown diagrammatically by Curves A, B and C respectively in Fig. 3.

It is remarkable that the short exposure of the fruit to 16.5% CO_2 in the case of Gas Series 5, mentioned above, resulted not only in the immediate

Scald at 4° C. (39° F.).			Core-flush at 4° C. (39° F.).			Fungal rotting at 4° C. (39° F.).		
4/11/31. 37 days. Note : No marked increase occurred after first examination until late in storage life.			20/6/32. 266 days.			20/6/32. 266 days.		
Prevalence.	Intensity.		Preva- lence.	Inten- sity.	Total amount.	Preva- lence.	Inten- sity.	Total amount.
0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	2
0	0	0	2	0.5	20	0	0	6
4	0.5	10	2	0.5	20	0	0	2
0	0	0	2	1.0	40	0	0	—
0	0	0	36	16	45	100	17	2
4	0.5	10	—	—	—	—	—	—
28	4.5	16	—	—	—	—	—	—
16	1.5	10	—	—	—	—	—	—
0	0	0	2	0.5	20	0	0	34

damage associated with exposure to concentrations of 15% CO₂, but also, in spite of the fact that subsequently the concentration of CO₂ never rose much above 10%, in the earlier onset of secondary injury, almost identical with that shown by the fruit exposed continuously to 15% CO₂. The behaviour of the fruit under these exceptional conditions is shown by Curve D in Fig. 3.

This result is of great significance to those interested in the overseas carriage of fruit.

Whilst the concentration of carbon dioxide appears to be the main factor responsible for breakdown and scald, the amount of oxygen present is not altogether without influence on the development of these functional diseases. The effect of oxygen can best be seen where the amount of injury is greatest, namely, where 15% CO₂ is present (Table II).

Storage at 4° C. (39° F.).

The effects of the gas-mixtures as shown by the change in ground-colour from green to yellow and by the softening of the flesh, was as marked at 39° F. as at 34° F. At this temperature, in sharp contrast to the results obtained at 34° F., neither breakdown nor scald developed in any atmosphere containing 5% CO₂ so that the commercial storage life of the fruit was considerably prolonged, not only as compared with fruit in air at the same temperature, but also as compared with fruit in air at 34° F. Thus the maximum storage life in air at 34° F. was 27 weeks and at 39° F. 24 weeks, whilst that of the fruit stored in 5% CO₂ at 39° F. ranged from 35 to 46 weeks, depending on the concentration of oxygen present (Tables IV and V).

At 39° F. the artificial atmospheres containing 10% CO₂ gave better results as regards commercial storage life than air at the same temperature and about the same storage life as air at 34° F. The shorter life with 10%, as compared

TABLE V.

Lane's Prince Albert Apples at 4° C. (39° F.).

Gas Series.	Oxygen %	Carbon dioxide %	Commercial storage life (in weeks).	Efficiency of gas mixtures. Air = 1.0.
1	2.5	5	> 46	> 2.0
2	5	5	46	2.0
3	10	5	35	1.5
4	2.5	10	30	1.3
5	5	10	30	1.3
6	10	10	24	1.0
7	2.5	15	7	0.3
8	5	15	4	0.2
9	10	15	4	0.2
10	21	0	24	1.0

with 5% CO₂, was not due to less retardation of ripening but was again due to the occurrence of traces of scald and breakdown late in the storage life of the fruit.

In the atmospheres containing 15% CO₂ a small amount of immediate damage, mostly scald, occurred, but it was sufficient on our assessment of commercial storage life (prevalence 10 per cent) to reduce the storage life to seven weeks or less. A study of the storage data given in Table IV reveals the same sort of relationship between carbon dioxide, oxygen, and the development of breakdown and scald, as was found at 34° F. Thus, as regards immediate damage, scald developed with 15% CO₂, but breakdown did not. The latter subsequently showed a slow development, more pronounced the lower the oxygen. There was no marked increase in the amount of scald after the first examination (37 days). Presumably a concentration of carbon dioxide in the region of 20 per cent would have been necessary to produce immediate damage from breakdown at this temperature.

The air-stored apples at 39° F. showed neither breakdown nor scald, their storage life being terminated by over-ripeness. At the sixth examination, after 38 weeks' storage, the wastage due to fungal rotting amounted to 68 per cent. At this time fungal wastage was negligible in all the artificial atmospheres.

The best gas-stored samples (i.e. those in 5% CO₂ and 2.5% or 5% O₂) were at this time green, crisp, acid and like normal unripe fruit. Moreover, a panel of judges reported on their cooking quality and found both texture and flavour after cooking excellent.

Whilst there was little in the results of the main experiment to distinguish between the two atmospheres, 2.5% O₂ with 5% CO₂ and 5% O₂ with 5% CO₂, evidence was obtained from the behaviour of these apples after removal from gas storage to air that the atmosphere containing 2.5% O₂ and 5% CO₂ provided the best storage conditions. The results of the chemical analyses, dealt with below, confirmed this judgment.

The loss in fresh weight after 46 weeks' storage in these two Gas Series amounted to approximately 5 per cent.

Storage at 10° C. (50° F.).

While the results obtained at 50° F. are of little practical value, they are interesting from the theoretical point of view, Table VI.

As regards immediate damage from carbon dioxide, the apples at 50° F. tolerated 15 per cent of this gas with all the concentrations of oxygen tested.*

* In Gas Series 4 (10% CO₂; 2.5% O₂) at this temperature a stoppage occurred in the ventilating circuit during the first week of the experiment during which the concentration of oxygen fell to less than 1.5 per cent whilst the carbon dioxide rose to over 15 per cent. This gave rise to some immediate damage from breakdown, which, however, did not subsequently increase.

TABLE VI.
LANE'S PRINCE ALBERT.

Gas Series.	O ₂ %	CO ₂ %	Internal Breakdown at 10° C. (50° F.).						Fungal rotting at 10° C. (50° F.).			Scald† at 10° C. (50° F.).
			4/11/31. 37 days.	3/12/31. 66 days.	13/1/32. 107 days.	1/3/32. 155 days.	1/3/32. 155 days.	1/3/32. 155 days.	1/3/32. 155 days.	21/4/32. 206 days.	21/4/32. 206 days.	
			Preva- lence. Total amount.	Inten- sity. Total amount.	Preva- lence. Total amount.	Inten- sity. Total amount.	Preva- lence. Total amount.	Inten- sity. Total amount.	Preva- lence. Total amount.	Inten- sity. Total amount.	Preva- lence. Total amount.	
1	2.5	5	0	0	0	0	0	0	0	0	4	4
2	5	5	0	0	0	0	0	0	0	0	28	0
3	10	5	0	0	0	0	0	0	0	0	16	10
*4	2.5	10	20	4	20	12	2.5	20	24	5	20	4
5	5	10	0	0	0	0	0	0	4	1	20	20
6	10	10	0	0	0	0	0	0	8	1.5	20	0
7	2.5	15	0	0	0	0	0	0	12	2.5	20	20
8	5	15	0	0	0	4	1	20	4	1	20	8
9	10	15	0	0	0	0	0	0	12	2.5	20	4
10	21	0	0	0	0	0	0	0	0	0	68	88

* The concentration of CO₂ exceeded 15% for 2 or 3 days during first period.

† This is the late type of scald usually associated with senescence.

Note.—Observations upon breakdown at the 5th examination (after 206 days) were impossible owing to the masking effect of fungal rotting.

Breakdown, however, developed to a slight extent in the presence of 15% CO₂ and 10% O₂ late in the storage life of the fruit, earlier than at 39° F., but actually at a later stage of ripeness.

TABLE VII.

Lane's Prince Albert Apples at 10° C. (50° F.).

Gas Series.	Oxygen %	Carbon dioxide %	Commercial storage life (in weeks).	Efficiency of gas mixtures. Air=1.0.
1	2.5	5	24	1.7
2	5	5	17	1.2
3	10	5	17	1.2
4	2.5	10	4	0.3
5	5	10	20	1.4
6	10	10	24	1.7
7	2.5	15	14	1.0
8	5	15	17	1.2
9	10	15	13	0.9
10	21	0	14	1.0

It will be seen from Table VII that the commercial storage life of the fruit in 15% CO₂ is approximately the same as in air, namely about 14 weeks.

In 10% CO₂ the storage life is considerably longer than in air at the same temperature, being 20 and 24 weeks for Gas Series 5 and 6 respectively. The air-stored controls ended their life from over-ripeness and fungal rotting, and were then very much softer and yellower than the apples stored in 10% or 15% CO₂ when the latter reached the end of their storage life.

Passing now to a consideration of the results obtained with 5% CO₂ we find no damage either immediately, or late in the life of the fruit, the end of the storage life being entirely due to fungal rotting. The maximum retardation and longest storage life were obtained with the lowest concentration of oxygen used.

The storage life of the fruit at 50° F. under the best gas conditions tested namely, 5% CO₂ and 2.5% O₂, was 24 weeks as compared with 14 in air; it was, in fact, almost identical with the storage life in air at 39° F. In other words, the effect of the artificial atmosphere upon the life of the fruit was equivalent to a difference in storage temperature of approximately 6° C. or 12° F.

A certain amount of superficial scald developed late in the storage life of the fruit at 50° F., but from the practical point of view this had little significance as it did not occur until some weeks after the limit of commercial storage life. Scald was most pronounced with 15 per cent carbon dioxide.

CHANGE IN GROUND-COLOUR.

In the series green to yellow Ridgway gives the following seven shades:

1. Green.
2. Yellow-green green.
3. Yellow green.
4. Apple green (Plate XVII, 29' in Ridgway's Colour Chart).
5. Green yellow.
6. Yellow-green yellow (Plate XVII, 25').
7. Yellow.

The range in colour-change of the Lane's Prince Albert apple during ripening is not very wide. The ground-colour in this variety throughout the commercial storage life at any temperature changes from apple green (shade 4 in the above series) at the normal time of gathering, to yellow-green yellow (shade 6).

At the beginning of April (i.e. after 27 weeks), the limit of the commercial storage life in air at 34° F. of the apples used in these experiments, the ground-colour fell half-way between shades 5 and 6. At this date the ground-colour of those gas-stored samples at 39° F., which had a longer storage life than 27 weeks, lay between shades 4 and 5 (Table VIII).

TABLE VIII.

Condition of cold-stored and of gas-stored Lane's Prince Albert apples at the end of the commercial storage life of the former (5/4/32).

Storage conditions.				Condition of the fruit on 5/4/32 (i.e. after 27 weeks' storage).	
O ₂ %	CO ₂ %	Temperature.		Ground-colour.*	Firmness of flesh.*
		°C.	°F.		
21	0	1	34	5.5	6.2
2.5	5	4	39	4.5	9.7
5	5	4	39	5	6.5
10	5	4	39	5	6.5
2.5	10	4	39	5	9.7
5	10	4	39	5	9.0

* See text.

At the end of their storage life (24 weeks) the apples stored in air at 39° F. had reached shade 6 on the above scale; those stored in air at 50° F. were also of this shade at the end of their storage life (14 weeks).

The ground-colour of the samples of apples from Gas Series 1 and 2 at 39° F., which had a storage life of at least 46 weeks, also reached shade 6 at this stage.

On analysing the effects of temperature, concentration of oxygen, and concentration of carbon dioxide on the progress of change in ground-colour, the outstanding fact which emerged was that at 39° F. and 50° F. the fruit in all the artificial atmospheres appeared to be greatly retarded in ripeness as compared with that stored in air, and the conclusion was drawn that this result was principally due to the carbon dioxide. Only in two cases was an effect of oxygen noticeable, namely, with a low percentage of carbon dioxide and 5% or 10% oxygen. The fruit in these atmospheres tended to yellow rather in advance of the other gas-stored samples.

The effect of temperature was pronounced, the higher the temperature, the more rapid the yellowing, both in the artificial atmospheres and in air.

CHANGES IN FIRMNESS OF FLESH.

The hardness of the fruit when gathered was not determined, but from observations upon similar fruit it can be stated that values of 9 to 10 lb. pressure would have been required on the penetrometer used in these tests. The diameter of the plunger fitted to this instrument was 7 mm., and the depth of penetration 7 mm. The skin of the apple to be tested was first removed by slicing off an area one-half to three-quarters of an inch in diameter.

Measurements were made on samples from all the Gas Series at the third, fourth and fifth examinations. The results showed that during this period, i.e., 107-206 days, there was little change under any particular conditions, but that prior to the third examination considerable differences in firmness of flesh had developed between the fruit under the various storage conditions.

TABLE IX.

°F.	2.5% oxygen.			5% oxygen.			10% oxygen.			Air.
	5% CO ₂	10% CO ₂	15% CO ₂	5% CO ₂	10% CO ₂	15% CO ₂	5% CO ₂	10% CO ₂	15% CO ₂	
34	9.1	9.6	9.3	9.1	9.6	9.6	8.2	9.1	10	6.5
39	9.2	9.7	9.6	6.9	9.4	9.5	6.3	9.4	9.7	6.1
50	8.2	10	9.7	6.3	6.9	8.4	6.4	6.5	7.3	5.4

Table IX gives the average values for hardness between the 107th and 206th days for all samples. It is evident that in general the gas-stored apples are considerably harder than the corresponding samples in air, and that both carbon dioxide and sub-normal oxygen retard the softening of the flesh.

Two samples of every Gas Series at each temperature were removed to air after $9\frac{1}{2}$ weeks' storage. Tests for hardness were made on these samples six weeks later. The results show that the effect of the artificial atmospheres in retarding softening of the flesh was maintained after removal to air. In fact, no significant difference in firmness of the flesh could be observed at that time between fruit which had been removed to air and that which had been in gas-storage throughout. Nine weeks after removal to air (i.e. 155 days from the beginning of the experiment) the second of the samples was tested for hardness. The values obtained are set out in Table X. A comparison of these values with those for the fruit gas-stored throughout (Table IX) showed that some softening had now occurred, but that the fruit still showed quite distinctly the effect of the nine weeks' gas-storage treatment, especially at the lower temperatures.

TABLE X.

°F.	2·5% oxygen.			5% oxygen.			10% oxygen.			Air mixture.
	5% CO ₂	10% CO ₂	15% CO ₂	5% CO ₂	10% CO ₂	15% CO ₂	5% CO ₂	10% CO ₂	15% CO ₂	
34	7·2	8·2	9·5	7·5	7·5	8·5	7	9	9·5	0·5
39	7	6·7	6·7	6·7	7	6·7	6·5	7	6·5	6·1
50	5·2	5·7	—	5	5·2	6	5·7	5·7	6	5·4

Essentially similar results were obtained with a further series of samples transferred from gas to air after 155 days (1/3/32).

BEHAVIOUR OF THE FRUIT AFTER REMOVAL TO AIR.

As stated above, two samples from each Gas Series at all three temperatures were removed to air at the same temperatures on two occasions ; after 66 days, and after 155 days. These samples were examined and compared with those gas-stored throughout on the dates of the two succeeding examinations in each case. Complete records of wastage and condition were made. The fruit was thus kept under observation for over three months after removal to air.

The results showed that the retardation of ripening established during gas-storage was maintained after removal to air. No development of breakdown or scald occurred subsequently in air. After three to four months in air this fruit occupied an intermediate position as regards ground-colour and hardness between the gas-stored fruit and that stored in air throughout.

One experiment was carried out in which a sample of fruit from each Gas Series at 39° F. was removed to a room at an average temperature of 60° F. on 20/4/32, i.e. after 206 days' storage. These apples were examined after one

month in air at 60° F. The condition of the fruit after this severe treatment is shown in Table XI.

TABLE XI.

Oxygen %	Carbon dioxide %	Percentage of fruit rotten.	Condition of sound fruit.
2.5	5	25	Sweet, juicy, crisp, firm, ripe.
5	5	50	Sweet, juicy, crisp, firm, ripe.
10	10	50	Very soft, juicy, full ripe.
21	0 (Air)	100	—

CHEMICAL CHANGES.

Chemical analyses were made of the ten sets of samples stored at 39° F. After each examination the cut halves were sent to the Low Temperature Research Station at Cambridge where they were immediately frozen at -20° C. (-4° F.). The analytical methods and the magnitude of the errors to be expected have been described elsewhere.* All determinations were made in duplicate.

In Tables XIII and XIV the results obtained with the fruit stored in air are compared with those obtained with the fruit stored under the best and second best conditions (i.e. 2.5% and 5% O₂ respectively with 5% CO₂ in each case) at the same temperature. In these tables the results with 10% O₂; 10% CO₂ atmosphere are also given, as they are of particular interest in view of the fact that this is the atmosphere used in the commercial gas-storage of Bramley's Seedling apples under the present system of control by regulated ventilation.

Two samples taken at the time of gathering gave the following results (Table XII).

TABLE XII.

	Sample I (% fresh weight).	Sample II (% fresh weight).	Average.
Alcohol-insoluble material (including starch) ..	1.89	1.91	1.90
Starch	0.14	0.15	0.14
Cane Sugar	2.13	2.17	2.15
Glucose Sugar	1.62	1.41	1.51
Fructose Sugar	5.01	5.00	5.00
Malic Acid	1.17	1.15	1.16
Nitrogen × 6	0.30	0.30	0.30
Total	12.12	11.94	12.02

* *Ann. Rpt. Food Investigation Board, London, 1931, pp. 74-5.*

TABLE XIII.
Showing loss with time in the various constituents of the apple at

Days.	Loss of total solids.				Loss of acid.				Loss of	
	Air.	Gas Series 1. 2.5% O ₂ , 5% CO ₂ .	Gas Series 2. 5% O ₂ , 5% CO ₂ .	Gas Series 6. 10% O ₂ , 10% CO ₂ .	Air.	Gas Series 1.	Gas Series 2.	Gas Series 6.	Air.	Gas Series 1.
66	0.487	+ 0.011	+ 0.168	0.158	0.14	0.12	0.13	0.23	0.97	1.23
108	0.698	0.384	0.289	0.531	0.24	0.19	0.20	0.29	1.40	1.55
155	1.209	0.636	0.825	0.805	0.40	0.31	0.35	0.36	1.58	1.67
206	1.526	0.793	1.187	1.648	0.52	0.34	0.40	0.50	1.73	1.71
267	2.265	0.888	1.372	1.928	0.60	0.44	0.54	0.61	1.81	1.79

TABLE XIV.
Showing loss with time in the various constituents of the apple at 39

Days.	Loss of total solids.				Loss of acid.				Loss of	
	Air.	Gas Series 1. 2.5% O ₂ , 5% CO ₂ .	Gas Series 2. 5% O ₂ , 5% CO ₂ .	Gas Series 6. 10% O ₂ , 10% CO ₂ .	Air.	Gas Series 1.	Gas. Series 2.	Gas Series 6.	Air.	Gas Series 1.
66	4.0	—	—	1.5	12	10	11	20	45	57
108	5.5	3.0	2.5	4.5	21	15	17	25	65	72
155	10.0	5.0	7.0	7.0	35	27	30	31	74	77
206	12.5	6.5	10.0	14.0	45	20	35	43	79	80
267	18.5	7.5	11.0	16.5	52	38	47	53	84	83

39° F. (Content per cent of original fresh weight.)

ane sugar.		Loss of total sugar and starch.				Loss of alcohol-insoluble material.		
Gas Series 2.	Gas Series 6.	Air.	Gas Series 1.	Gas Series 2.	Gas Series 6.	Air.	Gas Series 2.	Gas Series 6.
0.97	1.16	0.29	+0.06	+0.23	+0.06	0.05	+0.06	+0.01
1.37	1.52	0.37	0.21	0.08	0.24	0.08	0.01	±0.0
1.63	1.67	0.69	0.25	0.42	0.38	0.11	0.05	—0.06
1.67	1.73	0.85	0.42	0.74	1.06	0.13	0.05	0.08
1.76	1.82	1.51	0.46	0.76	1.23	0.15	0.07	0.09

7° F. (Expressed as loss per cent of original content.)

cane sugar.		Loss of total sugar and starch.				Loss of alcohol-insoluble material.		
Gas Series 2.	Gas Series 6.	Air.	Gas Series 1.	Gas Series 2.	Gas Series 6.	Air.	Gas Series 2.	Gas Series 6.
45	54	3.5	—	—	—	3.0	—	—
64	71	4.0	2.5	1.0	2.5	4.5	0.5	0
75	78	8.0	3.0	5.0	4.5	6.5	3.0	3.5
78	80	9.5	5.0	8.5	12	7.5	3.0	4.5
82	85	17.0	5.0	8.5	14	8.5	4.0	5.0

The change in these constituents during storage is shown in Tables XIII and XIV. Analyses are calculated in the first place as content per cent of original fresh weight. The results given in Table XIV are expressed as loss per cent of the original content of the particular constituent.

These results indicate that there was a correspondence between the effect of the artificial atmospheres in lengthening storage life, on the one hand, and in reducing the rate of loss of the carbon-containing constituents of the fruit by oxidation to carbon dioxide, on the other hand. Values for the average rate of loss per day per 100 grams of original fresh weight, obtained by the method of least squares, and values for the duration of commercial storage life in days are presented in Table XV.

TABLE XV.

O ₂ %	CO ₂ %	(a) Rate of loss at 39° F. (grams per day).	(b) Life duration at 39° F. (days).	a × b = loss at end of life. (grams.)
2.5	5	.0045	> 322	> 1.45
5	5	.0082	322	2.64
10	5	.0097	245	2.38
5	10	.0078	210	1.64
10	10	.0098	168	1.65
21	0 (Air)	.0093	168	1.56

The total loss during storage life can be obtained by multiplying together these two values. It will be seen that with the exception of two cases, namely, 5% O₂ ; 5% CO₂ and 10% O₂ ; 5% CO₂, approximately the same total loss occurred in each case.

In our earlier study of the Bramley's Seedling apple in gas-storage the chemical changes in the fruit during storage were followed on two occasions, but in both cases at 50° F.* It was found that an atmosphere containing 10% O₂ and 10% CO₂ halved the rate of loss of the carbon-containing constituents of the apple and correspondingly doubled the duration of its life. The results obtained with Lane's in this gas-mixture at 39° F. differ from those previously obtained with the Bramley's Seedling. With the Lane's Prince Albert variety the 10% O₂ and 10% CO₂ atmosphere did not lengthen the duration of life, and only slightly retarded the rate of loss. This difference between the results obtained with Bramley's and those obtained with Lane's may be attributed mainly to the difference in temperature between the two experiments. It is unfortunate that no chemical analyses were made of the Lane's gas-stored at 50° F. for, as can be seen from Table VII, the storage life of the Lane's in the atmosphere containing 10% O₂ and 10% CO₂ was, at this temperature, almost double that obtained with air-storage.

* loc. cit.

In Tables XVI to XIX the results of the whole series of analyses of the Lane's Prince Albert apples in the ten gas-mixtures at 39° F. have been brought together in such a way as to show separately the influence of carbon dioxide and of oxygen upon

- (1) rate of loss of carbohydrate (starch and sugars) in the process of respiration ;
- (2) rate of loss of acid by oxidation to CO_2 ;
- (3) rate of hydrolysis of cane sugar to reducing sugars, and
- (4) rate of loss of alcohol-insoluble material, i.e., by degradation, presumably by hydrolysis, of cell-wall material.

TABLE XVI.

Effect of CO_2 and of O_2 upon Loss of Carbohydrate, i.e. Starch and Sugars.

(Loss in grams per 100 grams original fresh weight of apple.)

Oxygen %.	Carbon dioxide %.	Days.			
		66	107	155	206
2.5 to 10	5	+0.25	0.02	0.31	0.51
	10	0.07	0.16	0.51	0.90
	15	0.15	0.40	0.67	1.11
Carbon dioxide %.	Oxygen %.				
5 to 15	2.5	+0.05	0.17	0.45	0.44
	5	0.13	0.25	0.56	1.03
	10	+0.11	0.17	0.47	1.04
Air mixture		0.32	0.43	0.78	1.05

TABLE XVII.

Effect of CO_2 and of O_2 upon Acid Loss.

(Loss in grams per 100 grams original fresh weight of apple.)

Oxygen %.	Carbon dioxide %.	Days.			
		66	107	155	206
2.5 to 10	5	0.13	0.21	0.33	0.38
	10	0.17	0.24	0.36	0.50
	15	0.18	0.27	0.42	0.53
Carbon dioxide %.	Oxygen %.				
5 to 15	2.5	0.11	0.24	0.35	0.44
	5	0.17	0.23	0.39	0.49
	10	0.20	0.25	0.38	0.49
Air mixture		0.12	0.19	0.31	0.34

TABLE XVIII.

Effect of CO₂ and of O₂ upon Hydrolysis of Cane Sugar.

(Grams hydrolysed per 100 grams original fresh weight of apple.)

Oxygen %.	Carbon dioxide %.	Days.			
		66	107	155	206
2.5 to 10	5	1.05	1.40	1.61	1.68
	10	1.15	1.49	1.73	1.78
	15	1.23	1.54	1.78	1.81
Carbon dioxide %.	Oxygen %.				
5 to 15	2.5	1.16	1.53	1.75	1.77
	5	1.17	1.46	1.73	1.76
	10	1.09	1.44	1.65	1.74
Air mixture		0.97	1.40	1.58	1.73

TABLE XIX.

Effect of CO₂ and of O₂ upon Loss of Alcohol-insoluble Material.

(Grams lost per 100 grams original fresh weight of apple.)

Oxygen %.	Carbon dioxide %.	107 days.	155 days.
2.5 to 10	5	0.02	0.05
	10	+0.01	0.04
	15	+0.06	0.03
Carbon dioxide %.	Oxygen %.		
5 to 15	2.5	+0.08	0.03
	5	0.01	0.04
	10	0.03	0.05
Air mixture		0.08	0.11

The following tentative conclusions may be drawn from the above tables with regard to the effects of oxygen and carbon dioxide at a temperature of 39° F. :

- (1) Increasing the concentration of carbon dioxide retards loss of carbohydrate ; 5 per cent gives greater retardation than 10 or 15 per cent ;
- (2) Increasing the concentration of carbon dioxide appears to accelerate loss of acid ;
- (3) Reducing the concentration of oxygen appears to have little effect upon the loss of carbohydrates or of acid ;
- (4) Increasing the concentration of carbon dioxide retards the loss of alcohol-insoluble material ;
- (5) Reducing the concentration of oxygen retards loss of alcohol-insoluble material ;

- (6) Increasing the concentration of carbon dioxide accelerates the hydrolysis of cane sugar ;
- (7) Reducing the concentration of oxygen has little effect upon cane sugar hydrolysis.

SUMMARY.

Within the limits of the conditions tested in these experiments the optimum conditions for the storage of Lane's Prince Albert apples appear to be a *temperature of 4° C. (39° F.) and an atmosphere containing 2.5 per cent oxygen and 5 per cent carbon dioxide.* Under these conditions of gas-storage the commercial storage life of the fruit was twice as long as that in air at the same temperature, and nearly twice as long as that in air at 34° F. (ordinary cold storage).

In conclusion the writers wish to acknowledge the valuable assistance of Mr. G. H. Crouch throughout these investigations.

BOOK REVIEWS

CLASSIFIED LIST OF DAFFODIL NAMES. Royal Horticultural Society, Vincent Square, London. 1933. 1s.

This valuable guide, containing an alphabetical list of over six thousand names is issued by the Royal Horticultural Society in its effort to stabilize daffodil nomenclature. The rate at which new varieties worth naming are being raised may be gauged from the fact that since the last issued in 1931 over three hundred new names have been registered of which a number have been received from the New Zealand Institute of Horticulture working in co-operation with the New Zealand Daffodil Society.

The system of classification used divides daffodils into eleven divisions each distinguished by some well marked character or group of characters, some of these divisions being again sub-divided. Its divisional number and sub-divisional letter precede each name in the alphabetical list so that by reference to the classification key a good idea of the flower can at once be obtained. In addition both the name of the raiser and the approximate age of the variety are indicated. Varieties now considered to be outclassed by more modern sorts are printed in smaller type.

It is obvious that confusion must arise if names are given to new hybrids without regard to those already in use. For this reason alone the list should be in the hands of all who raise, show or sell daffodils. But quite apart from its absolute necessity to the raiser of new varieties the book has a definite appeal and value to all amateurs and professionals who are at all interested in the flower.

INVESTIGATIONS ON THE STANDARDIZATION OF CITRUS TREES BY PROPAGATION METHODS. Imperial Bureau of Fruit Production: Technical Communication No. 3. Nov., 1932. 2s.

The most important progress made in recent years in regard to experimental work in the field of horticulture has been a realization of the necessity for using standardized material upon which to base the work. Much of the work done in the past is subject to serious experimental errors which have not been given due weight in the calculation of conclusions drawn as a result of the experiments.

The work of Hatton and others with deciduous fruit tree standardization through vegetative propagation of known varieties of stocks has led to a new

conception of the methods of conducting horticultural experiments, a conception which will undoubtedly result in far greater accuracy than has hitherto been possible.

While climatic conditions prevent the carrying out in England of field experiments with citrus trees, the Imperial Bureau of Fruit Production has rendered a valuable service to all horticultural students through compilation of the publication under discussion. Technical Communication No. 3 consists of five main sections comprising: variation in citrus orchards; polyembryony; vegetative methods of propagation of citrus; scion selection; rootstocks in use throughout the world.

Variation in yield in citrus groves is of vital concern both to the grower and to the investigator and the amount of variation that occurs is considerable. The main factors causing differences in amount of fruit borne by individual trees in a grove are: (1), the inherent qualities of the tree due to the character and of the stock and scion; (2), variability of the soil productivity. Variation in yield arising from variations in soil productivity (due to fertility, water relationships, physical characters, etc.) cannot be avoided but in experimental work, plots can be laid out in such a way that the degree of this variability can be calculated accurately.

Yield variations due to the character of the stock and scion can be greatly minimized through proper methods of stock and scion selection. The importance of such selection is realized by most horticultural investigators but a great deal yet remains to be done in bringing growers to appreciate the importance of planting trees of known inherent character and thus eliminating unnecessary variations in yield.

Control of variation with deciduous fruits due to the influence of the stocks used, has been shown by Hatton and associates to be possible through vegetative propagation (principally layering) of selected, known stock varieties. With citrus fruits, however, the problem is considerably simplified through the polyembryonic nature of the seeds of the common rootstocks. Several embryos are usually formed in a single seed and it has been shown by various investigators that the great majority of the embryos that give rise to young seedlings are of vegetative origin. "The economic significance of this phenomenon has not remained unobserved. Thus, if it is possible to distinguish the sexual seedling from the others in the seed bed, it would seem that nothing further should be needed to preserve a pure line of vegetatively reproduced descendants beyond the elimination of this seedling."

Webber, who can justly be looked upon as the doyen of all citrus investigators, considers that the sexual seedlings *can* be distinguished in the nursery by their physical characteristics. He says that "the variants are commonly, but not always, of comparatively small size and almost invariably produce

some degree of dwarfing in scions grown on them. The evidence available indicates that these variants are seedlings produced from the normal (sexual) embryos, probably mainly by self-fertilization. The roguing out of these variants from a batch of nursery seedlings before they are budded is the most important selection that can be made in the nursery. The seedlings remaining after such an elimination can be safely considered as being chiefly of apogamic origin."

Size differences in apogamic progeny occur as a result of environment and in addition to the elimination of the sexual variants there must be a selection within the apogamic population based on size at a given age.

A point which was not stressed in the publication under discussion and which is of considerable importance, is the necessity for consideration of the inherent characters of the parent tree from which the seed, ultimately to give rise to the selected, apogamic seedlings, is selected. In South Africa, for example, the rough lemon is almost the universal rootstock for citrus species and it is known that there are various types of rough lemons in existence. Different strains of rough lemon undoubtedly have different effects on the scions budded onto them. It would seem to be of vital importance that the nurseryman, as well as the investigator, should consistently use parent trees for seed which gives rise to apogamic seedlings that have a known effect on the varieties to which they are budded.

As an example of this point the writer can mention an orange grove in the Eastern Cape Province which is being adversely affected by irrigation with alkaline water. The grove consists of trees of a single variety from two different nurserymen, the trees from the two sources being planted in alternating rows. The trees from one nursery are showing alkali injury while those from the other nursery have not been affected. One nurseryman is apparently using a strain of rough lemon which is more subject to alkali injury than the strain used by the other nurseryman.

A discussion is given in this bulletin of the various rootstocks used in different citrus areas of the world and the general effects of each stock under the different conditions. Numerous species of *Rutaceae* are mentioned which are worthy of investigation as to their value as rootstocks for citrus.

Technical Communication No. 3 is a compilation in brief form and discussion of the available information on citrus rootstocks and methods of selection with a view to obtaining standardization of citrus trees used for experimental and commercial purposes. It is well written and a valuable publication with which every horticultural student should be familiar.

H. CLARK POWELL,

March 4th, 1933.

THE JOURNAL OF THE S.E. AGRICULTURAL COLLEGE, WYE, 1932.
Nos. 29 and 30. Edited by the Rev. S. G. BRADÉ-BIRKS. 2s. 6d.
and 7s.

The present issue of the Wye College Journal differs from its predecessors in that it is issued in two parts, the first issued in January, giving a brief account of the work carried out by the various departments of the college and the second, issued in July, devoted mainly to the publication of original papers. It is, therefore, the second part which will chiefly interest readers of this Journal. The variety of subjects dealt with is as usual very large and only those of interest to students of horticulture can claim mention here.

Mr. R. T. Pearl contributes a very useful review summary of the work carried out at East Malling on Apple Rootstocks Types I-XVI, giving the characteristics of each of the four groups in which the stocks are classed, as well as detailed descriptions of the individual stocks.

Messrs. Goodwin, Salmon and Ware describe experiments on the control of Apple Scab on certain varieties of apple, the experiments being carried out in a plantation near Sittingbourne and in the College plantations. The two latter workers also contribute an account of a hop disease, the cause of which is still unknown, in which there is a remarkable proliferation of buds on the rootstock, while the hop-cones never develop to the normal size.

Entomology is represented by a résumé by Professor F. Silvestri, of Italy, of three lectures on the Biological Control of Insects and Weeds which he delivered in London during the year. This aspect of Economic Entomology has been much to the fore recently, and although it is perhaps of less practical importance in this country than in certain others, Professor Silvestri's paper gives a most useful summary of the present state of our knowledge of the subject. Further information on the Strawberry Bud Weevil is given in an article by S. G. Jary. Unfortunately no efficient control measures for this pest, which often assume serious proportions, have yet been discovered. Although the winter washing of fruit trees to kill insect eggs has been practised as a routine measure in many plantations for a number of years, our knowledge of the precise action of the washes on the eggs concerned is still slight. Experiments have therefore been started at Wye to obtain some correlation between the chemical and physical properties of various oils and mixtures of oils and ovicidal efficiency in the field, and the results of the trials in 1931 are described by Messrs. Austin, Jary and Martin, and will well repay study by fruitgrowers.

It is impossible to mention, even by title, the accounts of work carried out by other departments of the College, but attention should perhaps be drawn to a useful table of cherry varieties, suitable for interpollination, drawn up by Mr. C. O. Hooper.

In conclusion it only remains to be stated that the Journal is, as usual, well printed and carefully edited, and is provided with an adequate index.

A.S.B.

THE HORTICULTURAL EDUCATION ASSOCIATION'S YEAR BOOK,
Vol. I. 1932.

To say that we welcome this new publication would be more polite than true. In these days the student of almost any subject looks darkly at the piles of literature which accumulate on his desk. Holidays themselves are poisoned by the thought of this vast inexorable flow converging relentlessly upon us. Our greeting to the newcomer is thus tinged by such reflections, but once fairly engaged we find much justification for its existence.

The articles cover a very wide range of commercial horticulture and the opinions are of interest and value.

Mr. Walter P. Wright with ripe authority displays the seamy side of landscape gardening as well as its brighter vistas. Dr. Bewley proves once again the fertility of the Cheshunt soil, the remarks upon strawing the ground in greenhouses are of the greatest importance and interest.

Mr. Boyes tells us of the ideals and achievements of the Cambridge Research Station but as one who has watched the Wisley Vegetable trials for over twenty years he seems to have had rather less than the usual luck in finding sources of reliable seed.

The Cauliflower Industry of Brittany is described by Mr. C. H. Oldham and Tomato Growing in Jersey by Mr. R. S. Thompson.

The influence of cultural practice on the storage qualities of fruit is ably summarized by T. Wallace and science confirms the popular experience that hard grown medium sized fruit is most suited for late keeping.

Mr. Bagenal describes the planting situation as a horticultural "gold rush," discusses its problems and future in a breezy style that Bret Harte would not have disowned. One does not envy those who are responsible for giving advice to these enthusiastic would-be planters, especially as in this country our experts are quite likely to be found in the same posts for several years. The frequent migration of horticultural authorities in the U.S.A. must have certain advantages for them at least.

Mr. Bagenal gives much good advice as to the buying of trees on value and not on price alone and raises many interesting questions which tempt a reviewer's pen. We will, however, only touch on one point—will Cox's Orange be overplanted—is it a "luxury" fruit for people of a refined palate only? History answers that every luxury fruit has become a popular one when its

price became low enough, the orange, grape and banana stand as witnesses. Cox's Orange has all the merits of a best seller, its merits are patent to the most uneducated of palates, the ready sale of those imported from Australia and Tasmania in the spring answers this question with loud affirmation.

The last contribution from the research department of Wye College is upon new insecticides and their contribution is both instructive and hopeful. Too long have our chemists left this question untouched and until the advent of Derris the question seemed almost at a standstill.

Space has not permitted any exhaustive recommendation of any of the questions dealt with in the numerous articles with which this year book is filled, but even the most harassed of students will find an hour well spent in looking through this volume and will congratulate the Editor on this maiden effort.

E.A.B.

OBSERVATIONS ON POTATO BLIGHT (*PHYTOPHTHORA INFESTANS*) IN RELATION TO WEATHER CONDITIONS

By MAUDE E. NAPPER, Ph.D.
Botany School, Cambridge

I. INTRODUCTION.

DURING the last few years much attention has been given to the study of *Phytophthora infestans* in attempts to elucidate the factors controlling the incidence of Potato Blight. It has long been known that attacks of this disease are associated with certain weather conditions, hence investigations have been made to determine the effect of various weather factors on its spread. A thorough understanding of weather conditions preceding outbreaks of Potato Blight might lead to ability to forecast epidemics by a study of meteorological data. This has already been attempted in Holland, as indicated by Wiltshire (13). In this way control of the disease by spraying would be made more certain, and crops would not be sprayed unless conditions warranted it.

Martin (9) found a correlation between the mean daily temperature and the rainfall, and the occurrence of epidemics of Potato Blight. Van Everdingen (12) stressed the importance of night dews, which provide the optimum conditions for the formation of zoospores of *Phytophthora infestans*. Beaumont (1) has shown that during the most active progress of a Blight epidemic, the temperature is fairly high and the relative humidity of the atmosphere is nearest its maximum. Wiltshire (13) has critically analysed the data hitherto available concerning the correlation of weather conditions with outbreaks of Potato Blight.

In researches on *Cystopus candidus* (11), the writer found that germination of the conidia and growth of the mycelium are controlled largely by the water-content of the host plant, which is controlled chiefly by the weather. Thus it was concluded that the key to the relationship between weather conditions and infection by *C. candidus* is the combined effect of weather factors on the water-content of the host plant. The present paper deals with investigations on *Phytophthora infestans* carried out along similar lines.

2. EXPERIMENTAL STUDIES.

(a) THE RELATIONSHIP BETWEEN THE WATER-CONTENT OF THE HOST AND THE GERMINATION OF CONIDIA.

The conidia of *Cystopus candidus* were found to germinate only after their maximum water-content had been considerably reduced, coincident with a diminution of the water-content of the surrounding host tissues.

Potato leaves gathered when their water-content was very high were inoculated with conidia of *Phytophthora infestans* and placed in a saturated atmosphere. When conidia were produced on the infected areas, germination tests were made, (a) immediately after removal of the leaves from the saturated atmosphere, and (b) after exposure of the leaves to a dry atmosphere for varying lengths of time. Six samples of conidia, taken from six different leaves, were used in each test. The results are given in Table I.

TABLE I.
The Effect on Germination of the Water-content of the Host Tissues.

Water-content.										Germination.
Maximum	..	..	..	..	..	..	..	..	..	None.
Approx. 4.5 per cent. below maximum..	..	..	..	..	..	..	..	..	..	High.
" 9	"	"	"	"	"	"	"	"	"	High.
" 15	"	"	"	"	"	"	"	"	"	High.
" 18	"	"	"	"	"	"	"	"	"	Trace.
" 22	"	"	"	"	"	"	"	"	"	None.
" 24	"	"	"	"	"	"	"	"	"	None.

This experiment was repeated twice, using conidia from leaves of other potato varieties. Similar results were obtained in the three experiments.

These results indicate that the conidia of *Phytophthora infestans* will germinate only when the water-content of their host tissues has been reduced about 4 to 18 per cent. below the maximum.

It is assumed in these experiments, as in those on *Cystopus candidus*, that the effect of a reduction in the water-content of the host plant is to decrease the water-content of the conidia by approximately the same amount, and that this partial drying of the spores is a controlling factor in germination. This assumption is partly based on the fact that when the conidia of *Phytophthora infestans* are exposed to a dry atmosphere while still connected with the host tissues, they do not dry out until the host cells become dried, whereas conidia removed from the host dry out almost immediately.

It seems evident that the water-loss necessary for the germination of conidia of *Phytophthora infestans* is less but of wider range than that necessary for conidia of *Cystopus candidus*, which germinate only when the water-content is reduced by about 30 per cent. below the maximum. This difference, together with the shorter incubation period in *P. infestans* than in *C. candidus*, may account for the more frequent epidemic attacks of the former fungus.

(b) THE EFFECT OF THE WATER-CONTENT OF THE HOST ON MYCELIAL GROWTH.

In experiments on *Cystopus candidus* it was found that mycelial growth was inhibited when the water-content of the host plant was low, and that the

fungus grew best when the water-content of the host plant was nearest its maximum.

The earliest experiments on *Phytophthora infestans* consisted of a number of unsuccessful attempts to establish the mycelium on the foliage of susceptible varieties in which the water-content was particularly low, the plants having been grown during dry weather. Similar experiments, carried out after a spell of very wet weather, produced abundant infection. In the latter experiments approximately equally mature plants of Up-to-Date (susceptible) and President (resistant) were inoculated. One hundred per cent. infection was secured in both cases, the lesions being smaller and the conidia less abundant in the resistant variety.

These results suggested that in *Phytophthora infestans*, as in *Cystopus candidus*, the water-content of the surrounding tissues is a controlling factor for mycelial growth. The following experiments were carried out in an attempt to obtain further evidence.

Experiment 1.

President leaves were gathered when their water-content was relatively high, and air dried for various lengths of time in order to provide a series of groups of leaves (five leaves in each group) with varying water-contents. These were inoculated with squares of infected leaf tissue bearing conidia of *Phytophthora infestans*. During the incubation period the leaves were kept in large Petri dishes lined with moist blotting paper, at a suitable temperature. The figures obtained in this experiment are given in Table II. In control experiments the conidia germinated and infection was absent in uninoculated leaves.

TABLE II.

Figures showing the Effect of the Water-content of the Host Tissues on Infection by Phytophthora infestans.

Water-content.				Infection (determined by comparing the leaf area bearing conidia with the total leaf area).
				Per cent.
Initial (water-content high)	..	..	..	30
4.5 per cent. below initial	..	..	..	10
9.0	"	"	"	0
15.0	"	"	"	0
18.0	"	"	"	0
24.0	"	"	"	0

Experiment 2.

Leaves of President, Up-to-Date and Kerr's Pink were gathered when their water-content was near its maximum. Inoculations were made as in the

previous experiment, (a) immediately after gathering and (b) after the leaves had been air-dried for a short period. The results of this second experiment are summarized in Table III.

TABLE III.

Further figures showing the Effect of the Water-content of the Host Tissues on Infection by Phytophthora infestans.

Water-content.	Infection (determined as before).		
	President.	Up-to-date.	Kerr's Pink.
(a) High	Per cent. 60	Per cent. 100	Per cent. 100
(b) Reduced slightly	50	95	90

These experiments show that the water-content of the host tissues influences the susceptibility of potato foliage to infection by *Phytophthora infestans*.

It was impossible to carry out similar experiments with tuber tissues, but it was found that the water-content of tubers of susceptible varieties was higher than that of resistant varieties. The figures obtained in this connection are given in Table IV.

TABLE IV.

The Relative Water-contents of Mature Tubers of Resistant and Susceptible Varieties of Potatoes grown under identical conditions (in adjacent rows).

Variety.	Water-content.
	Per cent.
President	71.5*
Up-to-date	79.8*
King Edward	81.2*

* Average of ten tubers taken from separate plants.

These data, supported by the results of experiments carried out by Collins (5), suggest strongly that varietal resistance to Potato Blight is due to the fact that the water-content of the foliage and tuber tissues of resistant varieties is lower than that of susceptible varieties grown under the same conditions. Hence a spell of wet weather, causing a similar increase in the water-content of both susceptible and resistant varieties, often brings the water-content of the former to a level above that necessary for the growth of the fungus, while the water-content of the latter remains below it. Very wet weather, sufficiently prolonged,

brings the water-content of the resistant varieties above this level, and under such conditions infection takes place readily in these varieties also.

3. DISCUSSION.

A review of the data recorded by other investigators on *Phytophthora infestans* reveals the existence of much evidence in support of the statement that the growth of the mycelium depends largely on the water-content of the surrounding medium.

Hecke (6), Jones, Giddings and Lutman (7), and Melhus (10) have found that *Phytophthora infestans* will grow on synthetic media only when the water-content is high. It is well known that the fungus grows most rapidly during particularly humid periods following heavy rains. Under such conditions little transpiration occurs, and the water-content of the host plant is very high. Beaumont (1) has shown that a close relationship exists between the incidence of Potato Blight and the relative humidity of the atmosphere. It has been observed also that plants growing on heavy soils and in low-lying, sheltered situations, are more susceptible to Blight than those growing on light, well-drained soils and in open situations, where the conditions are drier. Collins (5) has shown that the water-content of susceptible foliage is higher than that of resistant leaves.

Bottini (2), Laurent (8), Cercelot (4) and Capus (3) found that the susceptibility of the Vine to *Plasmopara viticola* is governed by the concentration of the cell sap, the tissues in which the water-content is highest being the most susceptible.

As stated above, the most important factor affecting the water-content of the potato plant is the weather. The parasite will not grow unless the water-content of the host is sufficiently high, so that in forecasting an outbreak of Potato Blight by consideration of meteorological data, weather conditions must be looked for which will bring about a high water-content of the host tissues. Such conditions would occur during a period of high rainfall with a moderate temperature, not high enough to reduce the relative humidity of the atmosphere sufficiently to cause excessive transpiration, but high enough for the fairly rapid absorption of water by the roots of the host and for the growth of the fungus. An absence of strong winds during this period would be favourable to the growth of the fungus because of the drying effect of wind.

Under these conditions also conidia would be formed rapidly. If the disease is to spread from plant to plant, the production of conidia must be followed by conditions favourable to germination, i.e. a spell of sunshine, a "drying" wind, or any combination of weather factors which would bring about a reduction in the water-content of the conidia. Wind would not only reduce the water-content of the spores, but would also disseminate them. Rain or heavy dew would be

necessary for the germination of the conidia. Subsequent weather conditions which promoted a high water-content of the host plant would favour the further development of the disease.

It appears then that an attack of Potato Blight is initiated by a period of heavy rainfall, high relative humidity, little wind and a moderate temperature. The progress of an attack is favoured by periods of high relative humidity and a moderate temperature, alternating with short spells of dry weather followed closely by rain or heavy dew.

Table V gives one set of data obtained by Mr. Beaumont at the Seale-Hayne Agricultural College, Devon, during an epidemic.

TABLE V.

Portion of Data showing the Relationship between certain weather conditions and the progress of an attack of Potato Blight.

Date (1930).	Per cent. relative humidity readings taken at intervals between 9 a.m. and 9 p.m.						No. of leaves infected in Plots of different ages.*							
							1	2	3	4	5	6	7	8
August 4	..	86	67	74	82	92	11	10	1	1	—	—	—	—
August 5	..	94	93	82	59	—	25	28	4	7	2	1	1	3
August 6	..	80	83	86	78	87	39	16	7	6	5	1	0	2
August 7	..	86	68	75	87	—	44	37	5	5	3	1	0	0
August 8	..	74	81	85	—	—	41	34	5	6	5	1	0	1
August 9	..	86	77	79	80	—	68	82	9	16	3	2	4	0
August 10	..	89	92	94	—	—	c.500	c.500	127	131	60	8	34	7
August 11	..	72	80	82	82	—	—	—	c.500	206	141	26	67	19
August 12	..	69	63	86	—	—	—	—	—	c.500	260	104	173	62

* Dates of Planting :

Plot 1 April 7.
 „ 2 April 22.
 „ 3 May 5.
 „ 4 May 19.

Plot 5 June 2.
 „ 6 June 16.
 „ 7 June 30.
 „ 8 July 14.

August 5th, 1930 was preceded by conditions described above as being favourable to the appearance of Potato Blight, and by this date Blight had appeared in each of the experimental plots. A spell of sunshine occurring during the late afternoon and early evening of August 5th reduced the relative humidity of the atmosphere to 59 per cent. This last reading of the day was taken at 8.30 p.m. Other data show that at 9 p.m. there was a strong breeze followed by a shower of rain. During the next few days the relative humidity remained high and the temperature moderate. The Table shows the increase in the amount of Blight in the plots under these conditions.

It was found by experiments carried out at the same time in adjacent plots that the incubation period of infection was four to five days in the older leaves, and longer in the younger ones. The large increase in the amount of infection at the end of similar incubation periods is shown in the Table.

4. SUMMARY.

1. A partial drying of the conidia of *Phytophthora infestans* is necessary for germination. The loss in water-content necessary for germination is less but of wider range than in *Cystopus candidus*.

2. Mycelial growth and conidia production depend upon the water-content of the host tissues. Hence the time and intensity of an attack of Potato Blight are largely controlled by the water-content of the host plant, and this depends chiefly upon weather conditions.

3. A period of heavy rainfall, high relative humidity, little wind and a moderate temperature predisposes the potato plant to an attack of Blight. The attack is intensified if this period is broken by a short spell of dry weather followed closely by wind and rain or heavy dew. Repetition of this sequence of events favours the further appearance of the disease in epidemic form.

5. ACKNOWLEDGMENTS.

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APPLE AND PEAR SCAB IN EAST ANGLIA

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THE following observations and experiments were made in the Eastern Counties for the purpose of obtaining more detailed information on the biology of the Apple Scab fungus (*Venturia inæqualis*) and the Pear Scab fungus (*Venturia pyrina*).

An attempt was made to find the time and origin of the early infection that takes place before blossoming, since to obtain a satisfactory control of apple scab it is important to prevent this early infection.

SPORE TRAPPING EXPERIMENTS.

In the West of England, Marsh (1) has shown by means of vaselined slides suspended in trees of Cox's Orange Pippin and Worcester Pearmain at the time when the first leaves were unfolding, that conidia were found afterwards on these slides, but no ascospores.

In our experiments the following methods of trapping spores were used :—

1. Traps of the wind vane type placed on posts about 4 feet high between rows of apple trees. From these traps we hoped to obtain information as to the number and type or types of spores present in the atmosphere over a given period.
2. Vaselined slides fixed by zinc strips parallel to young shoots bearing scab pustules. The slides were fixed so that they were from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches away from a scab pustule. The purpose of these was to obtain information concerning the discharge of conidia from the pustules.
3. Vaselined slides held by paper clips and these suspended by string about 4 inches from shoots. The purpose of these was to obtain information concerning the distribution of spores in the atmosphere near the leaves and flowers.
4. Vaselined slides fixed above overwintered leaves, these for the purpose of obtaining information on the discharge of ascospores from the perithecia in the dead leaves.

The slides were all lightly smeared with vaseline. After they had been exposed for the required period they were taken to the laboratory for examination or were posted by the County Horticultural Officers assisting in these experiments. One hundred randomized fields of view on each slide were examined.

Results from the Wind Vane Traps (1).

1. From four traps erected near Chelmsford, slides were replaced and examined weekly from February 26th until June 22nd by Mr. J. Bryce of the East Anglian Institute of Agriculture.

The first conidia were found on a slide on March 30th and after that date a very small number of conidia were found on the slides each week. No ascospores were found on any of the slides.

2. From four traps erected at the Hertfordshire Institute of Agriculture and Horticulture, Oaklands, St. Albans. The slides were placed in position on February 16th and examined weekly until June 21st.

Of the seventy-two slides examined only seven showed traces of conidia and no ascospores were found.

3. Traps were also erected near Cambridge, Wisbech, Kirton and in Norfolk but no conidia or ascospores were found on the slides.

Results from Slides fixed near Scab Pustules (2).

1. A number of traps were fixed in a ten-year-old grass plantation of Cox's Orange Pippin, Blenheim Orange, Beauty of Bath and Egremont Russet, at Cambridge, and these were kept under observation from February until September.

On February 17th some of the scab pustules on the twigs had ruptured and conidia apparently were ready to disseminate. It was not, however, until April 6th that conidia were found on slides in the traps near these pustules.

2. Ten twig traps were erected in trees at the Hertfordshire Institute of Agriculture and Horticulture, Oaklands, St. Albans.

The slides were placed in position on February 16th and examined weekly until June 21st.

The varieties of apple tree on which these slides were fixed were Stirling Castle, Newton Wonder, Beauty of Bath, Worcester Pearmain, Cox's Orange Pippin, Allington Pippin, Bramley and Bismarck. The first traces of conidia were found during the period March 8th to 15th on a slide fixed to a Cox's Orange Pippin shoot bearing pustules. The slides that were exposed subsequently on this shoot trapped large numbers of conidia until May 3rd when spray deposit was present. It is of interest to record that these trees were sprayed in the green flower and pink bud stage and to note that no spores were found subsequently on the slides exposed over this shoot. During the course of these exposures no ascospores were trapped.

3. Slides were exposed weekly from February 20th to June 22nd in a plantation near Chelmsford. Conidia were found first on those slides exposed from March 30th to April 6th. No ascospores were trapped.

4. Near Wisbech conidia were first found on slides examined on March 11th.

Results from Slides suspended from Shoots (3).

1. A number of slides were suspended from unsprayed trees in a grass orchard about ten years old near Cambridge; half of the orchard was composed of Beauty of Bath and Egremont Russet planted alternately and the other half of Cox's Orange Pippin and Blenheim Orange planted alternately.

The slides were exposed each week from May 16th to July 8th. In the first and subsequent weeks many conidia were trapped on the slides on Egremont Russet and Cox's Orange Pippin, but with one isolated exception spores were not trapped on Beauty of Bath and Blenheim Orange until the first week in June; and then, a relatively small number only were found, and there were fewer spores on the Beauty of Bath than on the Blenheim Orange. No ascospores were trapped in these experiments.

2. A number of slides were suspended in an orchard at Earith, Hunts., containing Allington Pippin, Lord Derby, Newton Wonder and Worcester Pearmain apple trees and Doyenne du Comice pears at Somersham, by Mr. F. Tunnington, the County Horticultural Organizer.

Periodic exposures were made from April 27th to June 13th, and conidia were trapped on the Newton Wonder, Cox's Orange Pippin and Doyenne du Comice slides at the first and subsequent exposures; on Lord Derby and Worcester Pearmain they were not trapped until the second week in May, and on Allington Pippin in the third week. No ascospores were found on these slides.

Results from Slides fixed above Overwintered Leaves (4).

1. *Apples*.—From slides fixed above overwintered apple leaves in a grass orchard consisting of Cox's Orange Pippin and Blenheim Orange, near Cambridge.

On February 17th these overwintered leaves contained apparently mature perithecia, but it was not until April 12th that a few ascospores were found on the slides on the ground. It is interesting to note that at this date the expanding buds were already infected by conidia.

Only in one or two cases were ascospores found on the slides fixed immediately above and in close proximity to overwintered leaves, and these were recorded on a slide that had been exposed from April 26th until May 3rd. No ascospores were found on the other slides placed in the vicinity of this one.

2. *Pears*.—Slides were fixed at varying distances from $\frac{1}{2}$ inch to 6 inches above leaves collected underneath Doyenne du Comice trees. Hurricane lamp chimneys were used for one set. The first ascospores were found on slides exposed from April 27th to May 4th. At this time scab was apparent on the pears.

On slides exposed from May 9th to May 17th a large number of ascospores were found on two slides fixed $\frac{1}{2}$ inch above leaves but none were found on the others.

Slides exposed on hurricane lamp chimneys containing leaves of Conference, Durondeau, Marie Louise, Pitmaston Duchess and Souvenir de Congres yielded no ascospores until April 22nd. At this time expanding buds of Durondeau were already infected by conidia.

FIELD INVESTIGATIONS.

Many of our observations were made in a grass orchard about ten years old near Cambridge, half of which was composed of Beauty of Bath and Egremont Russet, planted alternately, and the other half of Cox's Orange Pippin and Blenheim Orange, planted alternately. Some of these trees were used for spraying experiments.

First these trees were examined for scab pustules on the young shoots. The Cox's Orange Pippin and Egremont Russet were found to have severe infection on the one-year-old wood; a very slight infection was found on the one-year-old wood of the Blenheim Orange, but no trace of scab was found on the Beauty of Bath.

In our description we propose to use the terms dormant bud, bud burst, mouse-eared stage, green flower stage, pink bud stage, open flower stage, calyx stage, green marble stage, to represent successive stages in the opening of the flower bud.

It is of little significance to refer to dates of infection in terms of days and months, and consequently we propose to refer to the different stages in the maturity of the bud.

Infection of the expanding buds by conidia was found to take place rather earlier than we expected. Microscopic examination of some of the wood buds at bud burst showed that in some cases conidia were present on the young unfolded leaves. Shortly after bud burst conidia were also found on the young unfolded leaves of fruit buds.

Microscopic examination of fruit buds at the green flower stage showed that conidia were present entangled in the hairs on the sepals before these had bent back to release the petals. In the case of the wood buds we noticed that some of the buds of the one-year-old wood, which were situated near scab pustules, were infected by direct contact as the buds unfolded (see Fig. 1).

At this stage it was interesting to compare the results of the examination of the expanding buds with the results obtained from the spore trap experiments. Such infection was well developed on Cox's Orange Pippin and Egremont Russet before any ascospores were recorded on the slides placed above overwintering

leaves. It seemed evident, therefore, that the initial infection was brought about by conidia from the pustules on the wood and not from ascospores produced from overwintered leaves.

As the investigation proceeded it was seen that the Cox's Orange Pippin and Egremont Russet soon became severely infected and most of the trusses showed minor or major amounts of scab.

In contrast to the above, up to the time of blossoming very little scab was found on either Beauty of Bath or Blenheim Orange.

This difference we attributed to the presence of numerous scab pustules on the one-year-old wood of Cox's Orange Pippin and Egremont Russet and the absence of them on the Beauty of Bath and Blenheim Orange.

OBSERVATIONS AND EXPERIMENTS ON INITIAL INFECTION.

Since evidence that we had already obtained by examination of meteorological records showed that there was a correlation between rainfall and intensity of scab, and since our trapping experiments suggested that wind was not important in bringing about initial infection, we carried out some experiments to see how far spores could be splashed by falling drops of water. As a result of dropping forty-five drops of water, coloured with a dye, on to a glass surface from a height of 13 feet the ensuing splashes radiated about 3 feet from the point of impact.

Drops of water were allowed to fall from a height of about 3 feet on to scab pustules and as a result conidia of apple scab were found in the resulting splashes.

This lateral spread of conidia in rain drops is probably important in the primary infections in the case of apple scab. Marsh and Walker (2) say, "Under natural conditions the conidia are dispersed in wind-blown rain, and it is observed that the conditions required for dissemination of the conidia occur much more frequently than those required for germination."

This is another method by which the conidia are spread laterally. No additional evidence is necessary to show that water is of primary importance in the spread and growth of apple scab, but the following observation is of interest.

Cultures of apple scab were made from single ascospores obtained from overwintering leaves and after these had been grown for six weeks, the tubes were shaken over uncontaminated culture tubes. No infection of these resulted. Then drops of water were allowed to run down the culture and afterwards poured into clean culture tubes. Infection resulted. Moreover, although approximately 200 single spore cultures of scab were made, only in one or two cases did secondary infection of the same fungus arise in the culture tubes. This indicates that the spores are not readily released from their conidiophores. When, however, water

has been added to the culture of the fungus and then drained off, infection has subsequently resulted. Indeed, in some of the cases, the fungus has grown even at the bottom of the tubes between the medium and the glass.

Although rain could account for the primary infection of scab, it was difficult to understand how the severe and general attack could be accounted for unless the wood carried a very large number of pustules. Further examination of certain varieties showed that severe attacks of scab were present on some trees even when the pustules on the young wood were few in number. Further observations were then made to find the reason of the heavy infections on these trees.

APHIDES AS POSSIBLE CARRIERS OF APPLE SCAB.

Aphides present on badly scabbed trees were examined under the microscope and it was found that in a large number of cases, the conidia of apple scab were present on their legs (see Fig. 2).

This is probably one method by which secondary infection takes place, but aphides were not responsible for the heavy primary infection mentioned above, as in many cases no aphides were present on the trees until after this primary infection had taken place.

The presence of the conidia of apple scab on the legs of aphides led us to examine specimens of the leaf-curling plum aphid (*Anuraphis helichrysi* Kelt.) present on plum trees. On the legs of these aphides we found conidia of *Monilia cinerea*, the cause of the well-known "brown rot". This shows how brown rot may be spread by aphides and also offers partial explanation of the way in which tar oil washes indirectly reduce attacks of this fungus.

It is of interest to record that during the present season (1933) we examined some Egremont Russet trees and found that in the case of 100 trusses that showed severe aphid damage, seventy-seven showed very severe scab attack, and that in the case of 100 trusses that were free from aphid there were but twenty-eight trusses that showed scab damage and the extent of this was slight.

Whilst making these observations, one of us made an observation which provided a much more likely explanation of the heavy initial scab attack. This was the presence of scab pustules on the wood of a large number of fruit spurs (see Fig. 3).

In 1931 Salmon and Ware (3) observed the presence of scab pustules on the lowermost bud scales and on the one-year-old growths which constitute parts of the spur of the variety Worcester Pearmain. They emphasize the importance of the pustules on the bud scales.

In some of the spurs we examined the lesions made by the scab pustules had half girdled the one-year-old growths of the spur and gave an appearance somewhat similar to canker. The pustules were discharging spores and continued

doing so from the time they were first noticed in May until August, when observations ceased. During August some spurs were seen to be completely girdled by scab and consequently killed.

In the Cambridge plantation the Cox's Orange Pippin and Egremont Russet were badly infected with this spur scab. An examination of spurs taken at random from the four varieties gave the following results:—

<i>Variety.</i>						<i>Percentage of Scabbed Spurs.</i>
Cox's Orange Pippin	..	..	..	..	..	18
Egremont Russet	..	..	..	..	..	16
Blenheim Orange	..	..	..	..	..	0
Beauty of Bath	..	..	..	..	..	0

Observations carried out in Bedfordshire, Cambridgeshire, Essex, Hunts. and Norfolk showed that this spur scab is prevalent on certain varieties. The following showed heavy attacks of spur scab: Beauty of Kent, Bismarck, Cox's Orange Pippin, Devonshire Quarrenden, Egremont Russet, Golden Noble and Worcester Pearmain.

Pustules of pear scab were also observed on the spur wood of certain pears and were particularly abundant on Durendeu and Fertility (see Fig. 4). Shortly after finding these, Salmon and Ware (4) published a detailed account of similar observations in Kent and included a number of other varieties. They also found spur cankers on the resistant variety Conference.

The above observations suggest that "spur cankers" played a big part in the severe initial infection which took place in 1932. Observations made in unsprayed orchards supported this. Varieties which showed heavy scab infection always had an abundance of pustules on the young wood, usually on both the one-year-old shoots and on the one-year-old spurs. Varieties which had a slight scab infection had very few scab pustules or none at all.

In a systematically sprayed apple orchard in Cambridgeshire where no scab was found at the time of blossoming even on susceptible varieties, no pustules were found on the wood; on the other side of the road where no spraying had been done some trees were badly infected and these had both one-year-old wood infection and spur infection.

As mentioned above infection takes place very early and once the bud has burst it is liable to infection. In the case of wood buds on the one-year-old wood, these, on expansion, may be infected by direct contact with pustules situated just above the buds (see Fig. 1). Others may be infected by conidia washing down the stem, and others, again, by splashings either from pustules, or from conidia washed down the stem. Conidia were found first on the under side of

the leaves, which is according to expectation, as the leaves are curled inwards at the time of infection.

In the case of fruit buds conidia were found first on the lower surfaces of the leaves and as the leaves unfolded conidia were found in the middle of the truss entangled in the hairs of the calyces. At this stage the expanding fruit buds or flower truss usually consists of a central floret surrounded by a ring of florets. Surrounding the central floret is a circular groove almost V-shaped in section, and coated with the hairs from the outer surfaces of the sepals. Water is readily held in this groove and so provides excellent conditions for the further development of the conidia. The conidia on germination infect the outer surface of the calyx. As water drains off more readily from the outer surfaces of the florets conditions for infection are not so suitable on the outer sides of the ring of flowers as on the inside, and consequently infection is more likely to take place in the circular groove, i.e. the inside of the ring of flowers, than on the outside.

Apples formed from these flowers are therefore more likely to be infected on the sides facing the centre of the truss. This was confirmed by observations in the field.

After infection the scab fungus entrenches itself on the calyces. As the bud expands the sepals reflex to allow the petals to come out, and the scab infections are hidden from view as the outer surface of the calyx now becomes the lower surface. Infection now spreads directly or indirectly to the receptacle. Later, the sepals bend upwards again and scab spots can now be seen near the "eyes".

This characteristic of the sepals of bending back is likely to prevent spray fluid directed from above from reaching the receptacles or at least the top of the receptacle where the scab is situated, as the calyces act as umbrellas. We suggest that spraying in the calyx stage should not be directed downwards on the flower trusses but in a somewhat upward direction so that the receptacles can be more easily covered.

Field observations showed that the young wood of both the leaders and spurs become infected at an early date, while it is still green and succulent. As the fungus spreads on the leaves and fruit the conidia formed are washed down. The leaves are curled and form a suitable channel down which the water containing conidia can run. Conidia are thus carried to a position between the axil of a leaf and a developing bud, and bring about infection. Microscopic examination revealed the presence of conidia on the scale leaves of these developing buds. In the case of Fertility and Durondeau pears, infection was, in several cases, continuous from the "eye" of the pear down the inner side of the fruit and pedicel to the new wood of the spur, and in some cases this infection merged into the lesion that was present below the bud from which the new wood was formed.

THE PART PLAYED BY ASCOSPORES.

In 1924 Salmon (5) discovered the existence in this country of the perithecial stage of the scab fungus on leaves overwintering from the previous season. Since then a number of observers have found that this is common in various parts of the country.

In a paper read to the Association of Economic Biologists in 1929 Salmon says :—

“ Observers in the United States are agreed that dead scabbed leaves provide the main source of primary infection each season. There is little doubt, I think, that, in this country also, such dead leaves provide the main source on the farm. In our spraying experiments in Kent we have also been able to find in the orchard at the time when the first spraying was being carried out, dead leaves with ripe perithecia, which on being brought into the laboratory and kept wet soon discharged spores.”

Our observations showed that the ascospores produced in the perithecia of overwintering leaves were not the source of the primary infection in the orchards where we made our observations in 1932.

Observations made on the leaves of a number of varieties from various parts of the Eastern Counties showed the presence of perithecia containing viable ascospores, large numbers of which were discharged in the laboratory.

In one particular case a square inch of Emneth Early apple leaf from the Holbeach district of Lincolnshire was placed on the upper cover of a Petri dish and this rested 1 inch above a glass slide. The slide was changed and examined daily and the leaf moistened. The leaf bore immature asci on February 24th ; on February 29th these were mature and on March 5th they started to shed their ascospores, and continued doing so with the exception of two days until April 9th.

The tree from under which this leaf was taken had been sprayed with a tar distillate wash. The perithecia were apparently uninjured : the spores started to germinate four or five hours after they were shed. After five hours 10 per cent. had germinated, after sixteen hours 46 per cent. and after twenty-one hours 75 per cent.

It is of interest to record here our observations on the effect of spraying with a tar distillate wash on the formation of ascospores.

Some leaves that had obviously received drippings from the trees failed to develop mature perithecia. Other leaves from sprayed trees, however, developed normal perithecia.

On slides fixed closely above overwintering leaves of Cox's Orange Pippin in a grass orchard near Cambridge ascospores were first found on April 12th

although mature perithecia were present in the leaves in February. On April 12th the expanding buds on the Cox's Orange Pippin trees nearby were already infected by conidia. No ascospores were found on the slides suspended in neighbouring trees.

Slides suspended over pear leaves at Histon from March 24th onwards first showed ascospores on April 22nd and at this date the expanding buds of Durondeau were already infected by the conidia of pear scab. No ascospores were found on the suspended slides in neighbouring trees.

At Somersham slides suspended over pear leaves first showed ascospores on May 4th and at this date pear scab was apparent on the pears. In all our experiments only one ascospore was caught on slides suspended from the trees.

The above experiments show that ascospores were discharged from overwintering leaves and that they may be trapped on slides placed immediately above such leaves. They were, however, very seldom caught on slides hanging from the trees and in no case were they caught in the slides in the wind-vane traps.

From our observations, it would appear that the ascospores were not blown about freely in the trees during the time when the primary infection was taking place in the cases of both apple and pear scab.

The evidence put forward definitely proves that the ascospores played no part in the initial infection of apple or pear scab in the orchards under investigation in 1932, and that the conidia formed in pustules on the one-year-old wood or on the fruit spurs were responsible for the heavy initial infection.

SPRAYING EXPERIMENTS.

In the mixed grass orchard—about ten years old—near Cambridge, where many of our observations were made, we carried out spraying trials in the part of the orchard consisting alternately of Blenheim Orange and Cox's Orange Pippin. These trees had not previously been sprayed for scab. The plots, consisting of twelve trees except for occasional misses, were randomized and six plots were used for each treatment.

Treatment 1.—Five sprayings: three pre-blossom sprayings and two post-blossom sprayings.

First Spraying.—At mouse-eared stage (April 18th) Lime-sulphur 1 in 30.

Second Spraying.—At green flower stage (May 5th) Lime-sulphur 1 in 30.

Third Spraying.—At late pink bud stage* (May 18th and 19th) Lime-sulphur 1 in 30. Lead Arsenate powder 1 lb. to 30 gallons.

Fourth Spraying.—At calyx stage (June 6th and 7th) Lime-sulphur 1 in 100. Lead Arsenate Powder $2\frac{1}{2}$ lb. per 100 gallons.

Fifth Spraying.—At green marble stage (June 23rd and 24th) Lime-sulphur 1 in 100.

Treatment 2.—Four sprayings. As Treatment 1, with the omission of the first spraying.

Treatment 3.—Three sprayings. As Treatment 1, with the omission of the first two sprayings.

The controls were sprayed with Lead Arsenate on the occasions when Lead Arsenate was added to the Lime-sulphur. During the first week in August, 500 leaves were picked at random from both varieties, from four plots of each treatment, and from the controls, and the scabbed areas were measured.

Table I gives the results obtained from Cox's Orange Pippin.

TABLE I.
Cox's Orange Pippin.

	Plot No.	Scabbed area in cm. on 500 leaves.	Total scabbed area in cm. on 2,000 leaves.	Per cent. Scab compared with control.
Treatment 1	1	0.4	3.4	1.0
.. .. .	5	Nil.		
.. .. .	12	2.5		
Five Sprayings	13	0.5		
Treatment 2	4	0.6	2.9	0.9
.. .. .	6	0.1		
.. .. .	11	0.3		
Four Sprayings	15	1.9		
Treatment 3	3	20.0	43.0	13.3
.. .. .	7	12.0		
.. .. .	9	2.0		
Three Sprayings	16	9.0		
Control	2	85.0	323.0	100.0
.. .. .	8	120.0		
.. .. .	10	55.0		
.. .. .	14	63.0		

* This season the flowers passed through the pink bud stage much quicker than we had previously experienced and as a consequence this spraying was carried out later than we had intended. On most of the Cox's Orange Pippin a few flowers were open and on a few trees nearly 20 per cent. of them were open. The Blenheims were slightly more forward. This spraying caused a fair amount of leaf scorch.

Table II gives the results obtained from Blenheim Orange.

TABLE II.
Blenheim Orange.

	Plot No.	Scabbed area in cm. on 500 leaves.	Total scabbed area in cm. on 2,000 leaves.	Per cent. Scab compared with control.
Treatment 1	1	Nil.		
	5	2.0		
Five Sprayings	12	0.25	2.25	2.4
	13	Nil.		
Treatment 2	4	Nil.		
	6	Nil.		
Four Sprayings	11	1.25	1.25	1.3
	15	Nil.		
Treatment 3	3	Nil.		
	7	1.0		
Three Sprayings	9	Nil.	1.0	1.1
	16	Nil.		
Control	2	20.0		
	8	32.0		
	10	28.0	92.0	100.0
	12	12.0		

These experiments show that in the case of the variety Blenheim Orange, in which there were very few wood pustules present, one pre-blossom spraying in the late pink bud stage gave as good scab control as on the trees which were sprayed at the mouse-eared stage and at the green flower stage as well as in the late pink bud stage.

In the case of Cox's Orange Pippin where many pustules were present on the one-year-old wood or on the spurs, one pre-blossom spraying in the late pink bud stage gave a much inferior control than on the trees which were also sprayed in the green flower stage.

The first pre-blossom spraying in the mouse-eared stage had no influence on the control of scab although conidia had found their way to the buds at this date. It is unfortunate that our pink bud spraying was late, as one pre-blossom spraying correctly timed at the pink bud stage may have given a satisfactory control.

DISCUSSION.

Moore (6) has shown by experiments carried out over a number of years that one pre-blossom spraying at the "pink bud" stage and two post blossom sprays will give a good control of apple scab on Cox's Orange Pippin at East Malling.

As a result of his experiments in the West of England, Marsh (2) says, "Excellent control was obtained when sprays were applied at the 'green flower'

(=pre-pink), 'pink' and petal fall stages. When the first spray was applied before the 'green flower' stage the control was less effective."

Cheal's (7) experiments suggest that two pre-blossom sprayings (the first at the green flower stage and the second at the pink bud stage) followed by two post-blossom sprays give a better control of apple scab than one pre-blossom spraying at the pink bud stage followed by two post-blossom sprays on Worcester Pearmain at Wisbech.

Our observations on the method of primary infection suggest that while one pre-blossom spraying in the pink bud stage should be sufficient to give a satisfactory control of scab on trees where there is little or no wood infection two pre-blossom applications may give more satisfactory results on trees which have a heavy wood infection.

With wood-susceptible varieties even if one pre-blossom application correctly timed followed by two post-blossom applications is capable of giving a satisfactory control of apple scab, growers who take several days to spray all their trees will probably find an extra pre-blossom spraying well worth while.

Our observations suggest that the young wood of both the leaders and spurs become infected mainly by the washing down of conidia from the leaves and fruit. Post-blossom sprayings therefore are of importance in checking this infection on varieties on which wood pustules are formed.

Marsh (1) says, "Where trees have been practically freed from scab in one year it is possible to take considerable liberties with the spraying programme in the following year."

Our observations in commercial orchards suggest that when pre-blossom and post-blossom sprayings are carried out every year, starting when the trees are young, then scab is comparatively easy to control even on varieties subject to wood infection. In such circumstances very little scab is formed on the wood, and this where possible should be removed by pruning.

In the case of new plantations containing wood susceptible varieties such as Cox's Orange Pippin and Worcester Pearmain it is important to prevent the fungus from becoming established on the wood.

In planning a new orchard it must be remembered that wood susceptible varieties will probably need two pre-blossom sprays whereas those varieties which have no scab pustules on the leaders or spur wood will probably need only one. This suggests, unless other considerations necessitate modifications, that these two classes of varieties should be planted separately.

ACKNOWLEDGMENTS.

The authors are very much indebted to Mrs. W. A. R. Dillon Weston and the various County Horticulturists for their assistance in making the above observations, and to Mr. I. Thomas for his help during the spraying operations.

SUMMARY.

Results are given of various spore trapping experiments in East Anglia. These show that ascospores were rarely trapped in or near the trees and that they were not found until after the primary infection by conidia had taken place.

Observations showed that *pustules on the one-year-old spur wood* were common and together with the pustules on the one-year-old non-fruiting wood were responsible for the primary infection which took place very early. The importance of the lateral spread of conidia in splashes from rain is discussed.

Aphides are shown to be carriers of scab spores.

Spraying experiments show that scab is more readily controlled by one pre-blossom spraying on varieties which are not susceptible to wood infection than on wood susceptible varieties.

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FIG. 1.

Infection of wood buds of apple by direct contact.

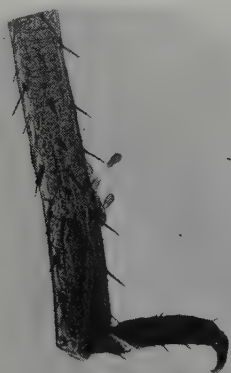


FIG. 2.

Hind leg of an aphid taken from an apple tree, carrying conidia of apple scab.

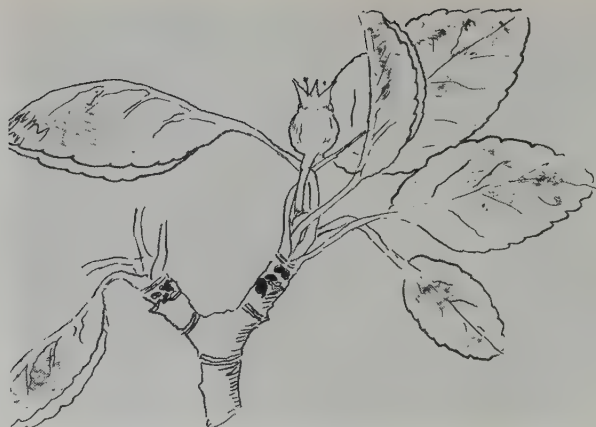


FIG. 3.
Scab pustules on the spur wood of apple.



FIG. 4.
Scab pustules on the spur wood of pear.

ABSORPTION OF POTASSIUM BY PLANTS AS AFFECTED BY DECREASED EXCHANGEABLE POTASSIUM IN THE SOIL

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THERE are strongly conflicting ideas expressed in the literature concerning the availability of potassium from the non-exchangeable or the residual minerals of the soil. Most investigators agree that most, if not all, of the exchangeable potassium is available to plants. Residual potassium is usually considered unavailable, because of the tenacity with which it resists the common reagents, such as carbonic acid, N/10 nitric acid, etc. The idea has been expressed by Gedroiz (1), however, that in some Russian soils at least, plants can obtain their potassium in adequate amounts even when the exchangeable potassium has been completely removed. Kelly (2) more recently has shown in field experiments carried out over a number of years near Fresno, California, that good crops of barley, cotton and alfalfa can be grown on a soil from which replaceable potassium has been leached with calcium sulphate almost to the vanishing point, thus supporting the pot results of Gedroiz. Grape vines are now planted on this soil and so far growth has been entirely satisfactory. It has also been reported by Hoagland (3) that certain Californian soils maintain continuously high potassium contents of the soil solution even though the exchangeable potassium is very low, and these seem to decrease little by ordinary cropping. It is a common observation that fruit trees usually fail to respond to potassium fertilization on many Californian soils where the exchangeable potassium is low, i.e. less than 100 p.p.m. of potassium. This phenomenon could be adequately accounted for if it could be shown that the minerals containing potassium were contributing it to the soil solution at a rate sufficiently rapid to supply the plant.

With this idea in mind, it was decided to attempt to obtain some information on the question of availability of non-exchangeable potassium by reducing the exchangeable potassium as far as possible by physical means and growing plants in the resulting low potassium soils. It was felt that the chemical method of Gedroiz was not suitable for the soils dealt with, as well as being too expensive for treating large amounts of soil. Since the largest amount of exchangeable potassium is found in the colloidal fraction, it was decided to reduce that fraction of the soil as far as practicable. Accordingly two soils were selected from the

* This work was done at Long Ashton Research Station, University of Bristol, while National Research Fellow in the Biological Sciences.

soil fertility plots of the Agricultural and Horticultural Research Station at Long Ashton for these trials. One was taken from a plot on which apples were making a satisfactory growth and showing no signs of potassium starvation. The other was obtained from a nearby plot on which apple trees originally similar in every respect to those on the good plot were making very unsatisfactory growth and exhibiting marked symptoms of potassium deficiency. The appearance of trees on these plots is shown in Figs. 1 and 2. Before planting to orchard trees, these plots for a large number of years had formed part of a meadow which was ploughed out in 1924 and subsequently cropped annually with oats until 1927 in order to utilize a proportion of the turf residues. The area covered by the second plot, which is low in potassium but high in nitrogen, had given the better results with oats, the relative performances of oats and apples thus being reversed on the two plots.

The experiment was regarded as complementary to other investigations, carried out simultaneously, the principal object of which was to examine the potassium status of orchard soils, especially with regard to supplies of water soluble and replaceable potassium, in cases of severe potassium starvation of fruit trees (4).

EXPERIMENTAL.

The soils were treated by adding rain water to about 400 lb. of soil, agitating thoroughly, allowing the coarser particles to settle and siphoning off the supernatant colloidal suspension. This process was then repeated. The result was a soil not very different from the original in texture, barely measurably different in fact as determined by mechanical analyses, but greatly reduced in exchangeable potassium. The figures are as follows: Exchangeable potassium, plot A1, before treatment, 400 parts per million of dry soil; after treatment, 160 p.p.m.: plot A2, before treatment, 200 p.p.m.; after treatment, 120 p.p.m. The 1:1 water extract gave 30.0 p.p.m. before treatment, 3.7 p.p.m. after treatment, and 5.0 p.p.m. before treatment and 2.1 p.p.m. after treatment respectively for these samples. In both cases the soil used was from the top 3 inches.*

After drying and screening, the soil was placed in paraffin treated flower pots, 7 kilograms being used in each pot. The plant selected for the first trial was buckwheat (*Fagopyrum esculentum*). Seed was sown on September 9th, 1931. A month later differential nutrient treatments were started. The series set up for each soil were as follows: untreated soil, designated C; treated soil with no added nutrients, designated TC; treated soil receiving Wallace's solution D (complete nutrient minus potassium) designated TD; treated soil receiving

* Values for the top 9 ins. on the two plots were as follows:

A1.	exchangeable K	200 p.p.m.	1:1 water extract:	K 2.5 p.p.m.
A2.	"	K 100 p.p.m.	1:1 " "	K 1.6 p.p.m.

Wallace's solution A (complete nutrient solution) designated TA. The prefix Ar or A2 is used to designate the two soils.

On October 13th the plants in each pot were reduced in number to a maximum of eight. On October 23rd the weather became too severe for the plants to be left in the unheated greenhouse where they were started, and the experiment was transferred to a heated greenhouse. A week later, October 29th, flowers appeared on some plants in each series. On December 9th the plants were harvested. The tops were cut off at the surface of the soil and analysed. The roots were neglected. The results of this trial are reported in Table I.

TABLE I.

Results of Pot Experiments with Buckwheat showing Potassium Absorption under Varying Conditions of Supply.

Series.	Total fresh Weight in gms.	Fresh Weight per Pot in gms.	Total Dry Weight in gms.	Dry Weight as % of Fresh Weight.	Total Weight of Ash in gms.	Ash Weight as % of Dry Weight.	Total Weight of K ₂ O in mgs.	Weight of K ₂ O per Pot in mgs.	K ₂ O as % of Ash.	CaO as % of Ash.	MgO as % of Ash.
ArC	105	17.5	19.5	19.3	3.11	15.8	576	96	18.5	26.6	4.7
A2C	158	26.3	25.0	15.8	4.42	17.7	874	146	19.9	21.3	8.0
ArTC	118	17.0	23.0	19.5	3.06	13.3	541	77	17.7	26.5	5.7
A2TC	147	18.4	23.0	15.6	3.78	16.4	627	78	16.6	29.3	4.3
ArTD	133	19.0	20.0	15.0	3.46	17.3	599	85	17.3	20.0	7.0
A2TD	220	27.5	33.0	15.0	5.57	16.9	878	110	15.8	27.2	7.9
ArTA	155	22.1	22.0	14.2	3.63	16.5	689	98	19.0	22.4	10.5
A2TA	224	28.0	32.0	14.3	5.62	17.5	1,007	128	17.9	30.3	4.7

It will be seen from this table that even where the exchangeable potassium content is lowest, this element does not limit growth. The plants have been able to secure an adequate supply of potassium in all cases, and show no evidence of potassium deficiency. The nitrogen supply seems to be the limiting factor to growth in all cases. Soil A2 has a higher nitrogen content than has Ar (0.305 per cent. and 0.161 per cent. respectively) and the results of this test reflect that difference. It is interesting to note that in spite of the fact that the percentage of potassium in the ash is slightly less in the plants grown on soil A2, the total potassium extracted by the plants as expressed in milligrams per pot is greater in plants grown on soil A2 except those in the unfertilized washed soils.

Following the trial with buckwheat, a second experiment was started in the same soil. Seeds of a selected strain of tomato (*Lycopersicon esculentum*) were planted on the 1st of January. The plants were transferred to small pots on January 28th. On April 2nd they were removed from these pots, the roots washed and the plants set in the larger pots. A sample of the plants taken at

this time showed them to have an average fresh weight of 3.4 grams, dry weight of 0.4 gram, ash weight of 0.0779 gram, and K_2O content of 0.0139 gram.

The plants were not permitted to develop side shoots, and all flowers were removed as they appeared. The rate of development as measured by height of plant was surprisingly uniform for the plants in any one group. As early as the end of May, differences began to appear between the plants in soil A1 and those in soil A2. The foliage of the latter plants was of a darker green colour and larger. This tendency became accentuated as time progressed. Typical plants are shown in Fig. 3 as they appeared at the time of harvest. The series receiving only water showed marked symptoms of nitrogen deficiency, especially those in the A1 soil.

TABLE II.

Results of Pot Experiments with Tomato showing Potassium Absorption under Varying Conditions of Supply.

1	2	3	4	5	6	7	8	9	10	11	12
	Total Fresh Weight in gms.	Fresh Weight per Pot in gms.	Total Dry Weight in gms.	Dry Weight as % of Fresh Weight.	Total Weight of Ash in gms.	Ash as % of Dry Weight.	Total Weight of K_2O in gms.	Weight of K_2O per Pot in gms.	K_2O as % of Ash.	K_2O in Basal lea. es.* gms.	8 plus 11
A1C	375	62.6	60	16.0	6.76	11.3	1.66	0.28	24.6	0.24	1.90
A2C	568	94.6	124	21.9	13.96	11.2	2.81	0.47	20.1	0.28	3.09
A1TC	510	72.9	105	20.8	11.00	10.4	2.77	0.40	25.2	0.46	3.23
A2TC	501	71.6	98	19.7	10.58	10.8	2.26	0.32	21.3	0.28	2.54
A1TD	1,106	184.3	219	19.8	22.52	10.3	5.88	0.98	26.1	0.75	6.63
A2TD	1,583	226.1	289	18.3	30.23	10.4	5.66	0.81	18.7	0.49	6.15
A1TA	1,775	253.5	335	18.9	34.41	10.3	10.05	1.44	29.2	1.11	11.16
A2TA	2,226	278.3	407	18.3	44.80	11.1	11.02	1.38	24.6	0.99	12.01

* These leaves were shed during the growth period.

At the time of harvesting, July 4th, the poorest growth was made by plants in series A1C. The yield and potassium content are given in Table II. They were smaller, both in height and in size of leaf than those plants in other series. All of the plants in the various "C" series showed marked symptoms of nitrogen deficiency. The addition of nitrogen did not give as good results as the addition of nitrogen plus potassium, as measured by fresh and dry weight. It seems that these plants were actually experiencing some potassium deficiency although there was no leaf scorch, even in the A2TD series.

Following the removal of the tomato crop, the soils were tested for exchangeable potassium. The results showed in all cases sharp reductions in the amount present compared with the beginning of the experiment. The figures show that

in all of the treated series except the A₂TA, there was an appreciable contribution from the non-exchangeable potassium in the soil. The amount of potassium absorbed from the non-exchangeable fraction of the soil can be calculated by subtracting the total exchangeable potassium at the beginning of the experiment from the sum of that left after removal of two crops and the amount absorbed by the plants. This figure is not quite accurate since the potassium in the root systems was not determined but should be included in the amount absorbed. This error does not affect the conclusion, however, since it minimizes the amount attributed to the non-exchangeable fraction.

The untreated soils and the completely fertilized A₂ soil have apparently supplied the plants exclusively from the soluble and exchangeable potassium. The others show contributions from the non-exchangeable fraction as follows :

A ₁ TC	..	..	..	..	425	mg.	per	pot.
A ₂ TC	..	..	..	..	42	..	..	
A ₁ TD	..	..	..	..	778	..	..	
A ₂ TD	..	..	..	..	542	..	..	
A ₁ TA	..	..	..	..	115	..	..	

DISCUSSION.

The data are interesting in their relation to the potassium supplying power of the soil. They show that neither the exchangeable nor the water soluble potassium is an accurate measure of the ability of a soil to supply the potassium needs of a plant. Taken in conjunction with the field performance of trees on the same soils, they bring out clearly the fact that different plants do not have the same ability to withdraw potassium from the soil. This has, of course, been recognized by many previous workers, and is common field experience.

These results emphasize the fact that no criterion is at present available to predict the ability of a plant to obtain adequate potassium from a soil except to grow the plant on it. The exchangeable fraction is probably the most useful chemically determined portion of the soil potassium from this standpoint, but it has serious limitations. Unpublished data obtained by Lilleland at the University of California support these conclusions.

SUMMARY.

Data are presented which show that different plants vary widely in their ability to withdraw supplies of potassium from a given soil; that neither exchangeable nor water soluble potassium is an accurate index of the soil's ability to supply potassium, and that the non-exchangeable potassium may be a very important source of supply to some plants in certain soils.

ACKNOWLEDGMENT.

The writer wishes to acknowledge his indebtedness to the Agricultural and Horticultural Research Station of the University of Bristol at Long Ashton who very kindly supplied the necessary facilities for this work ; to Dr. T. Wallace, who supervised the care and harvesting of the tomato plants after my departure ; to Mr. W. H. Neild for assistance with the pot cultures ; to Mr. F. C. Lewis who analysed these plants ; and to Mr. E. A. Wilkins, who made the final exchangeable potassium determinations.

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FIG. 1.

Lane's Prince Albert apple on Plot A1, Long Ashton. Tree 4 years old. Normal growth, adequate potassium supply.



FIG. 2.

Lane's Prince Albert apple on Plot A2, Long Ashton. Tree 4 years old. Stunted growth, potassium

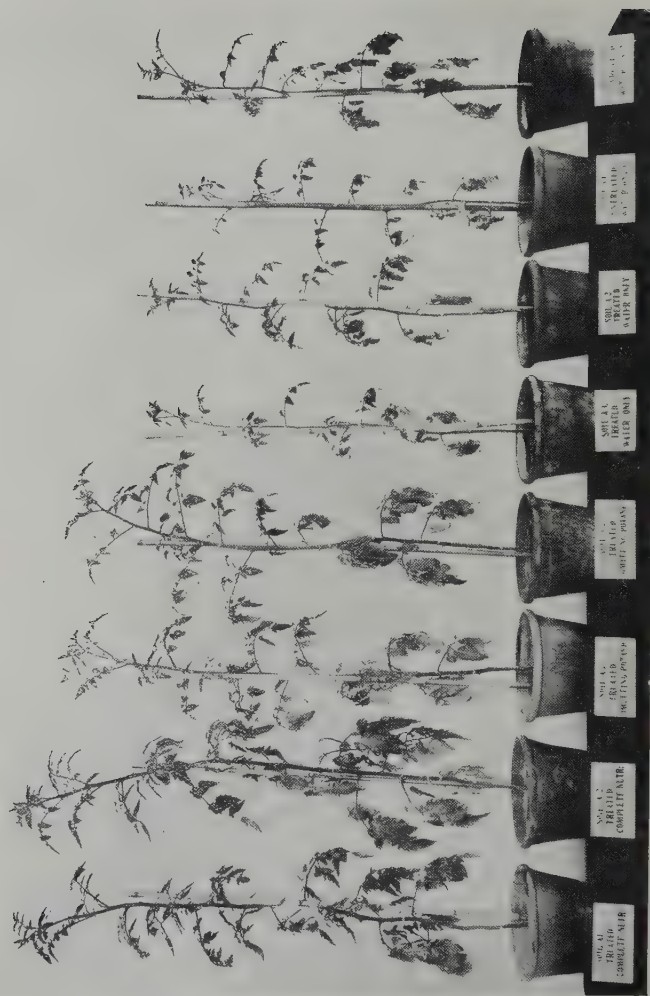


FIG. 3.

Tomato plants at time of harvesting.

From left to right : Soil A1 treated, complete nutrient ; Soil A2 treated, complete nutrient ; Soil A1 treated, nutrient minus potassium ; Soil A2 treated, nutrient minus potassium ; Soil A1 treated, water only ; Soil A2 treated, water only ; Soil A1 untreated, water only ; Soil A2 untreated, water only.

CANKER AND DIE-BACK OF APPLES ASSOCIATED WITH VALSA AMBIENS

By LAWRENCE OGILVIE
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IN the spring of 1930 the attention of the writer was drawn to a large number of cases of sudden dying off of branches of apple trees or of entire trees. The situation will perhaps be best understood if several of these cases are described in detail.

CASES OF DIEBACK IN APPLE TREES.

CASE 1. BURGHILL, HEREFORD.

On June 3rd, 1930, five Newton trees in this orchard were found to be apparently dying off, all the leaves and flower trusses having suddenly wilted. In all these cases there was a definite wedge-shaped canker at the base of the trunk, extending upwards and reaching through the bark to the wood.

Underneath the external cork layer were found developing pustules of a fungus resembling a *Cytospora*. On July 1st, 1930, the bark on the cankered areas had an opaque whitish brown appearance, and the cork layer peeled off easily like paper, exposing a greenish-white to brown mealy-like area, often with brown striations and somewhat water-soaked. Underneath this the bark was dead right down to the wood. The whole of the affected bark was water-soaked and had a somewhat aromatic smell.

On all these cankers there were found, early in July, a few inches back from the apex of the cankers, numerous pustules of a species of *Cytospora* from which yellow spore-tendrils were exuding.

The soil was a shallow one, liable to become waterlogged, and it should be stated that over twenty of the neighbouring trees in the same orchard showed slight to severe leaf scorch symptoms early in July. The less severely affected trees recovered completely in the course of the summer.

CASE 2. BLAKENEY, GLOS.

This orchard of Allington and Early Victoria was situated at the top of a ridge on shallow soil on the top of a marl. According to the owner the trees appeared to be perfectly healthy till early in May, 1930. On May 5th, eight of the trees or separate branches of the trees had a wilted appearance, as if they had been burned.

Here, also, in every case the affected trees, which were scattered throughout the orchard, had cankered areas progressing upwards from the bases of the trunks, and in cases where only one branch of the tree had died off the canker was

situated below this branch. The symptoms in the diseased region were precisely similar to those in Case 1, and *Cytospora* sp. was present in every case.

On May 27th several of the affected trees appeared to be recovering.

CASE 3. COLWALL, WORCS.

Four fairly old trees, two Worcester and two Beauty of Bath, were examined on June 10th, 1930. These had exhibited a similar failure of branches when the flowers were in the "pink bud" stage, but on June 10th fresh buds were appearing on several trees. The bark was now splitting along the edges of the cankered areas. *Cytospora* sp. was also found on the cankers in these trees, and its yellow spore-tendrils were being produced abundantly on June 10th. The trees were all growing in a badly drained situation.

CASE 4. STAWELL, SOMERSET.

A bush tree, near a headland, had been burned at the tips of the branches by a fire. The bark at the ends of the branches was peeling off like brown paper, and numerous fructifications of a *Cytospora* were present.

CASE 5. MICKLETON, GLOS.

The branches of several Worcester trees were severely affected with *Nectria* canker. The tips of such branches, above the cankered areas, bore fructifications in January, 1933, of a *Cytospora* and also of a *Valsa*.

A similar fungus, *Cytospora* sp., has been found on a large number of other occasions under circumstances similar to those detailed above.

ISOLATION OF THE FUNGUS.

The *Cytospora* was isolated very easily on malt-extract agar plates, and the isolations were found in every case to be identical.

INOCULATION EXPERIMENTS.

Inoculations were attempted in July, 1930. Incisions were made in the bark of a 3 feet high Bramley tree growing in a pot in the greenhouse, and pieces of mycelium from a malt-extract agar culture were inserted. No cankers were produced.

Following a suggestion contained in a paper on *Valsa Mali* in Japan by K. Togashi (19), a further series of trials was carried out in 1931 as follows:—

A series of twenty-four small Allington and Bramley trees were planted up in a plot of good soil at Long Ashton and were inoculated on December 1st, 1932, as follows: (1) Incisions were made in twenty-four twigs, and pieces of mycelium of the *Cytospora* sp. from a culture were inserted in them; (2) incisions were similarly made in other twenty-four twigs but no cultures were inserted;

(3) thirty-five twigs were slightly charred on an area about 1 inch long by means of a small lamp, and pieces of mycelium were then inserted as above.

In the following April it was observed that all the inoculations on the burnt areas had been successful, and that typical cankers were being produced with the characteristic symptoms of peeling off of the cork layer and the development of a water-soaked appearance of the bark accompanied by *Cytospora* pustules, from which tendrils of yellow spores exuded. All the inoculations on the unburnt bark were unsuccessful, and the uninoculated incisions also remained perfectly healthy.

All the successful inoculations girdled the twigs, resulting in the death of the distal parts, and extension of the cankers continued throughout spring and summer. By late autumn it had ceased and measurements were made (on December 1st) of the extent to which the cankers had progressed down the twigs. The greatest length covered was 17 cm., the average being 4.8 cm. By this date also all the successfully inoculated twigs were covered with the perithecia of a *Valsa* sp. Cultures from the ascospores of this fungus were identical with those of the *Cytospora*, and produced *Cytospora* pycnidia and typical yellow spore tendrils. It was therefore concluded that the *Valsa* was the perfect stage of the *Cytospora*.

THE FUNGUS IN CULTURE.

The mycelium of the *Cytospora* on malt-extract agar is at first white and flocculent, becoming Tilleul buff to sepia (Ridgway). Olive-grey tumuli develop over the surface of the mycelium. These are the pycnidial stromata from which exude the spore tendrils which are at first whitish and finally an opaque waxy yellow. The under surface of the cultures is almost black.

On sterile apple wood a copious flocculent white mycelium is developed. On the surface of the wood round black pycnidia, about 1.5 mm. in diameter, usually covered with olive grey mycelium, are produced. From these the spore tendrils exude.

These characteristics differ strikingly from those of *Valsa Mali* Mbe. and Yamada and *Leucostoma Persooni* (Nitsch.) Togashi (*V. leucostoma* Pers.), cultures of which were obtained for comparison, through the kindness of the Ministry of Agriculture's Plant Pathological Laboratory.

DESCRIPTION OF THE FUNGUS.

The following description was prepared from fructifications on twigs that had been inoculated with pure cultures. Fifty measurements of spores and asci were made :—

Pycnidial stromata thickly scattered over the bark, 0.5-1 mm. in diameter, covered, then erumpent. Disc round, flattish, brownish. Ostiole black, scarcely

protruding. Pycnidial loculi several, labyrinthiform, the walls composed of dark brownish tissue. Pycnosporos, allantoid, $4.6-1\mu$, av. 4.8μ (mode 4.8μ) $\times$ $0.8-1.3\mu$ av. 0.96μ (mode 0.9μ), exuding in whitish, and finally yellow, tendrils. Sporophores verticillate, acicular.

Perithecia often surrounding pycnidial stromata, sunken in the unchanged bark parenchyma, spherical, with conical necks. Average diameter of perithecium 68μ , height 58μ , length of neck 72μ . Asci club-shaped, sessile, 4- or 8-spored (usually the latter), $48-64\mu$, av. 56μ (mode 56μ), $\times$ $6.4-9.6\mu$, av. 8.2μ (mode 8μ). Spores arranged irregularly or in pairs, cylindrical, usually curved, hyaline; in the 8-spored asci, $12-20\mu$ long, av. 15.4μ (mode 16μ) $\times$ $2.7-4\mu$, av. 3.2μ (mode 3.2μ). In the 4-spored asci the spores are much broader (av. 4.8μ).

This description agrees well with the diagnosis of *Valsa ambiens* (Pers.) Fr. as given by Togashi (19) and others quoted by him, and does not agree with that of *V. Prunastri* (Pers.) Fr., *V. Mali* Mbe. and Yamada, or *Leucostoma Persooni* (Nitsch.) Togashi. The diagnosis of the pycnidial stage agrees well with that of *Cytospora ambiens* Sacc. (Sacc. Syll., Vol. 3, p. 274), the species generally considered to be the pycnidial stage of *Valsa ambiens*. The description of *C. carphosperma* Fr. is very close, and Grove (8) considers that the latter name should be confined to the form of Tilia.

PREVIOUS REFERENCES TO *VALSA AMBIENS* IN ENGLAND.

Valsa ambiens has been recorded by Saccardo (17) and others as occurring on a very wide variety of host plants, the relative measurements varying somewhat with the host. It is a common fungus in this country and has been listed from various tree hosts among the finds at forays of the British Mycological Society, e.g. :—

Drumadrochit	1908	(Trans. Brit. Myc. Soc., Vol. 3, p. 58).
Worcester	1912	(" " " " Vol. 4, p. 19).
Keswick	1922	(" " " " Vol. 9, p. 9).
Bristol	1923	(" " " " Vol. 9, p. 132).
Bristol	1929	(" " " " Vol. 15, p. 9).
Whitby	1930	(" " " " Vol. 16, p. 14).

The last two records were from elm.

Although the fungus appears to be very common on apple there have been few references to its occurrence on this host in England, the only two known to the writer being by Plowright in Grevillea, 1887 (15) and Cooke (3) in his *Fungoid Pests of Cultivated Plants*, quoted later by Massee (12).

Plowright made abundant collections of *Valsa ambiens* on apple around Terrington St. Clements, near King's Lynn, in 1885. These were distributed as *Valsa ambiens* var. *Mali* Sacc. in the following published exsiccata :—

Plowright, *Sphaeriacia Britannici*, II, 31.

Vize, *Micro-fungi Britannici*, 163.

Cooke, *Fungi Britannici Exsiccati*, Ed. II, 472.

Cooke refers to the species in a paragraph entitled "Apple-bark *Valsa*". He considers the fungus to be the cause of a bark disease, and states that the conidial stage is *Cytospora carphosperma* Fr. The fungus is said to be "common on many orchard trees, but heretofore considered saprophytic. The mature condition [*Valsa ambiens*] is to be found in spring on branches that have lain on the ground throughout the winter. . . ."

PREVIOUS REFERENCES TO SIMILAR DIE-BACK DISEASES.

There have been many papers on the occurrence of similar Die-Back diseases in stone fruits, and much controversy as to whether the associated fungi (*Valsa* or *Cytospora* spp.) are primarily responsible. For references to these diseases the reader should consult Togashi's publications (19, 20, 21, 22).

Another similar disease is the Canker of poplars and willows associated with *Cytospora chrysosperma*, concerning which the papers by Long (11), Hubert (9) and Povak (16) should be consulted. In this case the fungus appears to be secondary to injury of some sort.

Voglino (24) found *Valsa ambiens* associated with a Die-Back of Canadian poplar (*Populus virginiana*) in Piedmont, while *Valsa* and *Cytospora ambiens* have been recorded from diseased chestnuts by Dufrenoy (5) and by Verplancke (23).

There are comparatively few references to Die-Back diseases of apples associated with these fungi. As we have seen, Cooke (3) considered *Valsa ambiens* to be responsible for a bark disease, but apparently not on the basis of any experiments.

Aderhold (1) made inoculations of *Valsa leucostoma* upon apple, and in 1900 recorded it as the cause of cankers on pear.

Van der Bijl (25) and Evans (6) noted *Cytospora leucostoma* as the cause of Die-Back of apple trees in South Africa, while Darnell-Smith and Mackinnon (4) reported *Valsa* and *Cytospora* on apple in New South Wales. Nicholls (14) reported the death of apple trees in Tasmania associated with *Valsa Prunastri* and *Valsa ambiens*.

In leaflet No. 87 (second edition, 1920) issued by the Ministry of Agriculture (13), and entitled "The Die-Back (*Cytospora*) Disease of Fruit Trees", there is the

following interesting reference to the disease on apples, "In the case of apple trees the disease may start on the branches and spread downwards, producing somewhat similar effects to those described for peach trees. The colour of the diseased branches varies from a lightish to a dark purple. Not infrequently, however, in the case of apples, the fungus first attacks the main branches, or even the trunk of the tree near the ground, and produces cankerous wounds. This form of attack is very much more serious than the ordinary form of die-back since the disease extends more rapidly in the tissues, and if the trees are not immediately attended to they may be completely killed within a year or eighteen months. The disease is attributed to *Cytospora leucostoma* or other species."

In 1919 F. L. Stevens (18) published a paper on "An Apple Canker due to *Cytospora*". The cankers were on twigs of young trees in Illinois. No attempt was made to inoculate the fungus into healthy trees. The fungus agreed well with the *Cytospora* stage of *Valsa leucostoma*. Leonian (10) described a similar disease in 1921. The trees affected were attacked by root borers or by woolly aphids. The disease appeared to spread up the trunk from the base. In addition to *Cytospora* fructifications, perithecia of *Valsa leucostoma* were discovered. Inoculations with pure cultures were unsuccessful on healthy trees, but were successful on trees previously debilitated.

Togashi (19) in 1924 gave a very full description of a Japanese apple Canker which he found to be due to the fungus *Valsa Mali*. The symptoms resemble strikingly those noted by us for *Valsa ambiens*; the fungus is, however, quite distinct. Togashi concluded from inoculation experiments that *Valsa Mali* is the direct cause of an apple canker in Japan, but that the fungus is a wound parasite, requiring for its establishment old wounds or dead back caused by winter injury, wind injury, pruning, insects, etc.

Britton-Jones (2), in 1925, found *Diaporthe perniciosa* and a *Cytospora* sp. associated with a dying back of twigs and branches of apple trees, apparently initiated in every case by some physiological factor, e.g. excessive or insufficient soil moisture.

In 1931 Fisher and Reeves (7) published an account of a Canker of apple trees in Washington State, U.S.A. This Canker was also associated with a species of *Cytospora*. The trees had suffered severely from drought in the previous season. Enlargement of the cankers continued till the latter part of May, when the affected areas began to be delimited and eventually all the dead areas healed over completely. Artificial inoculations produced negative results on sound apple wood and also on wood which had been winter injured but not killed.

The majority of the writers on this group of diseases on apple trees, and those who have investigated the subject most carefully, have therefore concluded

that *Valsa* and *Cytospora* species are not primary invaders of healthy tissues, but that they attack some local necrotic area, thence spreading slightly into normal tissues.

DISCUSSION.

The large number of cases of Die-Back of apples observed by the writer in 1930 is considered to have been associated with the exceptionally wet winter of 1929-30. Waterlogging was common in heavy soils, as shown by the prevalence of dying off of "Lloyd George" raspberry stools, which are highly susceptible to such conditions. Waterlogging at soil level gave rise to small dead areas of bark which the fungus was able to enter and thence invade healthy wood to some extent. In some cases, the presence of the advancing wedge-shaped area of infected wood and bark resulted in wilting and death of branches above; or, if the trunk in question was girdled, in death of the whole tree. In many cases, however, the diseased area ceased to spread in the course of a few months, became delimited by cracks, and subsequently callused over. This was followed sometimes by renewed growth of the wilted branches.

Twig and branch infections were in all cases strictly local, following on some previous wound, and caused very little damage.

SUMMARY.

1. Cases of Die-Back of apples occurring in 1930 after heavy winter rainfalls are described. These were associated with ascending wedge-shaped cankers at the bases of the trees, on which fructifications of a *Cytospora* sp. appeared. The same *Cytospora* was found on small cankers associated with various forms of branch injury.

2. Inoculations of pure cultures of the *Cytospora* into healthy twigs were unsuccessful, but when small areas of the twigs had been previously burned the fungus penetrated several inches into healthy wood.

3. *Cytospora* pustules were produced on the inoculated twigs and subsequently perithecia of *Valsa ambiens* (Pers.) Fr. appeared. A single spore isolation of the latter gave identical cultures which produced *Cytospora* spores.

4. The *Cytospora* was identified as *C. ambiens* Sacc.

5. A review is given of previous references to *V. ambiens* in England and of similar diseases associated with species of *Valsa* and *Cytospora*.

6. It is considered that *Valsa ambiens* is a weak parasite incapable of attacking healthy trees but capable, when once established in necrotic areas, of invading healthy tissue to some extent.

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BREEDING EXPERIMENTS WITH "PARADISE" APPLE ROOTSTOCKS

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LITTLE precise information has, so far, been obtainable upon the inheritance of characters in seedlings of the cultivated apple. Some American workers have reported upon evidences among apple seedlings of a segregation of factors for vigour and certain characters of the fruit such as colour, shape and size (1, 2, 3, 4, 5).

Upon the other hand, the cytology of the apple has been extensively studied both in this country and abroad. The work of Darlington and Moffett (9, 10, 11), and that of Nebel (6) and Rybin (7, 8) has shown that all varieties of the cultivated apple are either diploid or triploid in their chromosome constitution. The former workers have advanced the theory that all the varieties of the Pomoideæ are secondary polyploids. All the varieties of the Malling series of so-called Paradise Apple Rootstocks so far examined have been found to be diploids. Crane and Lawrence (12) have shown that the triploid varieties of apples are characterized by a high degree of sterility which is reflected in their offspring and also in the progeny resulting from diploids crossed with triploids. Seedlings obtained from such crosses are very lacking in vigour.

The seventeen varieties of apple rootstocks now collectively known as the Malling series of Paradise Rootstocks are, in certain cases, reputed to be of ancient origin. Bunyard (18) describes the history of certain of them and cites Molon as placing several as botanical sub-varieties of *Malus pumila*. They were collected together at East Malling in 1912 and 13 from English and Continental sources and subjected to a rigid classification on botanical and pomological characters by Hatton and his co-workers (13, 14, 15). Clonal races of most of these types were later raised and worked with several of the most widely used commercial varieties. It was quickly found that the stocks differed widely in the influence which they exerted over the scion variety budded or grafted on them (16, 17).

When once the potentialities of the rootstocks at present in commercial use had been sufficiently explored it became desirable to breed new varieties which would combine attributes possessed severally by two or more varieties in the existing series or have qualities not at present represented. With this object, a number of families of seedlings, the result of cross-pollinations between varieties of the "Paradise" Rootstocks have been raised, both at the John Innes

Horticultural Institution, with whom this Station is working in close collaboration in its rootstock breeding projects, and at East Malling itself. The work of testing these seedlings is considerable. In the first place they are grown in the nursery and subjected to the "stooling" method of vegetative reproduction, by which the average nurseryman raises the majority of his rootstocks (19). In this way all those seedlings which do not give rise to numerous and well rooted stocks can be eliminated. Those seedlings which survive this initial test are then budded in quantity with a variety with whose behaviour on the commoner varieties of "Paradise" we are familiar, and closely watched over a period of years for preliminary indications as to their growth, precocity in fruiting and other characters.

THE MATERIAL.

During the Spring of 1929 a series of families of seedlings were raised by the writer comprising crosses between Malling No. IX and Nos. I, II, IV, V, VI, VII, XII, XIII, XV and XVI. In all cases except the last the crosses were made reciprocally. A brief description of each of these rootstocks is given.

No.	Common Name.	Growth on its own roots.	Influence on the scion variety.
I	Broadleaved English.	Fairly vigorous.	Makes a fairly vigorous tree.
II	Doucín.	Rather dwarfed.	Usually rather less vigorous than I.
IV	"Malus pumila."	Rather dwarfed.	Makes a fairly vigorous tree.
V	Improved Doucín.	Rather dwarfed.	Slightly less vigorous than II.
VI	Nonsuch Paradise.	Fairly vigorous.	Makes a fairly vigorous tree.
VII	No name.	Medium growth.	Similar to II in growth.
IX	Jaune de Metz.	Dwarfed and stunted.	Makes very dwarfed trees.
XII	Seedling of English origin.	Very vigorous.	Makes very large, vigorous trees.
XIII	" " German "	Very vigorous.	Makes a fairly vigorous tree.
XV	" " " "	Very vigorous.	Makes a fairly vigorous tree.
XVI	" " " "	Very vigorous.	Makes a fairly vigorous tree.

The pollinations were made upon trees growing out of doors and the usual methods of isolation, emasculation and pollination were employed, the flowers being protected from contamination by the use of fine muslin bags. In Table I the proportions of fruits set to flowers pollinated, the numbers of seeds obtained and their germination are set out in detail. The very high percentage of fruits set is partially accounted for by the fact that, in all cases, the trusses were reduced to a single flower. While the figures show considerable variation, in the majority of cases No. IX used as pollen parent gave a better set of fruit than where it was used as the seed parent. Thus, when No. IX was used as the pollen parent, a total of 336 flowers gave rise to 137 fruits, or 40.7 per cent., while, when No. IX was used as the seed parent, a total of 345 flowers gave

TABLE I.

Details of Pollinations, Numbers of Seeds per Fruit and Germination.

Nos.	No. of flowers polltd.	No. of fruits set.	% of fruits set.	No. of seeds obtained.	Average No. of seeds obtained per fruit.	No. which germin- ated.	% germina- tion.	No. of sdgs.
I × IX	41	19	46.3	87	4.6	73	83.9	71
IX × I	36	16	44.4	118	7.4	78	66.1	76
II × IX	—	—	—	91	—	44	48.3	40
IX × II	—	3	—	20	6.7	9	45.0	7
IV × IX	54	25	46.3	146	5.8	106	72.6	100
IX × IV	60	22	36.6	124	5.6	60	48.4	53
V × IX	32	12	37.5	74	6.2	52	70.3	49
IX × V	36	6	16.7	36	6.0	16	44.4	16
VI × IX	39	16	41.0	90	5.6	77	85.5	75
IX × VI	57	25	43.9	159	6.4	111	69.8	109
VII × IX	30	20	66.7	83	4.1	67*	80.7	56
IX × VII	50	14	28.0	101	7.1	80*	79.2	69
XII × IX	18	2	11.1	14	7.0	10	71.4	10
IX × XII	5	4	80.0	17	4.2	5	29.4	5
XIII × IX	46	4	8.7	19	4.7	17*	80.5	16
IX × XIII	50	12	24.0	51	4.2	28*	54.9	23
XV × IX	51	30	58.8	166	5.5	135	81.3	130
IX × XV	51	19	37.2	113	5.9	67	59.3	67
XVI × IX	25	9	36.0	50	5.5	41	82.0	40

* Chlorotic seedlings occurred in these families. The numbers were as follows: VII × IX, 12 seedlings, IX × VII, 16 seedlings, XIII × IX, 1 seedling, IX × XIII, 4 seedlings.

118 fruits, or 34.2 per cent. Certain exceptions occurred as in the cases of the crosses between Nos. XIII and IX which gave a low proportion of fruits set whichever way the cross was made. In general, however, No. IX, whether as seed or as pollen parent, was completely fertile when crossed with these ten varieties and cases of marked incompatibility were not encountered.

Excluding the crosses between Nos. II and IX for which data is not available, a total of 255 fruits contained 1,448 seeds, or an average of 5.6 seeds per fruit. In many cases where No. IX was used as the seed parent the fruits contained a larger number of seeds than was the case where it was used as the pollen parent; this is most notable in the crosses between No. IX and Nos. I, VI and VII. Taking all the families together, when No. IX was used as the seed parent, 118 fruits contained 719 seeds, or an average of 6.1 seeds per fruit. In the crosses in which No. IX was used as the pollen parent, 137 fruits contained 729 seeds, or an average of 5.3 seeds per fruit. Actually, the number of seeds contained in No. IX fruits varied widely, being greatest in the cross with No. I, in which there were, on the average, 7.4 seeds per fruit and least in the crosses with Nos. XII and XIII, in which the fruits contained an average of 4.2 seeds. Wide variations also occurred in the average number of seeds contained in the fruits of the other rootstocks when crossed with No. IX.

No. XII had outstandingly the greatest average number of seeds per fruit and No. VII the least.

The fruits were stored throughout the Winter of 1929-30 and the seeds were extracted and sown during the Spring of 1930. As may be seen from Table I, germination varied from less than 45 per cent. to more than 80 per cent. All the families in which No. IX was the pollen parent germinated better than those in which it was the seed parent, although in certain cases, such as the crosses between II and IX and VII and IX the difference was very slight. Grouping the families together, in those cases in which No. IX was used as the pollen parent, 820 seeds produced 622 seedlings, or a germination of 75.7 per cent. Where No. IX was used as the seed parent, 739 seeds produced 454 seedlings, representing a germination percentage of 61.4. Six of the ten families in which No. IX was the pollen parent had a higher percentage germination than No. IX $\times$ No. VII, the family which had the highest germination percentage among the crosses in which No. IX was the seed parent.

Among seedlings of the four families, VII $\times$ IX, IX $\times$ VII, XIII $\times$ IX and IX $\times$ XIII, a proportion occurred which were lacking in chlorophyl. They were whitish yellow in colour and only rarely survived beyond the cotyledon stage. Certain of those in families VII $\times$ IX and IX $\times$ VII, however, later formed green leaves and, although their development was somewhat retarded, they survived. Both in the crosses between VII and IX and in those between XIII and IX the proportion of normal to chlorotic seedlings was approximately 5 : 1, viz. :—

				Normal.	Chlorotic.
VII $\times$ IX and reciprocal	..	..	..	119	28
5 : 1 ratio	..	..	..	122.5	24.5
XIII $\times$ IX and reciprocal	..	..	..	40	5
5 : 1 ratio	..	..	..	37.5	7.5

The seedlings were planted out into small pots as soon as they were large enough to handle and were later planted in an uncovered frame at approximately 12 inches by 9 inches apart. Half the seedlings in families XV $\times$ IX and IX $\times$ XV were handed over to Mr. A. M. Massee, of the Entomological Section, for artificial inoculation with Woolly Aphis. He found that all these seedlings were susceptible to attack by this insect. Of the parent varieties, Le Pelly (21) found both susceptible to attack when artificially inoculated. Subsequent work by Massee has shown that while No. XV is by no means resistant, it is less susceptible than No. IX. During the ensuing Winter all the seedlings were removed and planted out in the open field at two foot six inches apart in each direction. Here they remained untouched for one year and, during the following Winter, were cut down to just above ground level, being later mounded up as stools.

TABLE II.
*Vigour of the Seedlings as expressed by Wood Growth, Girth of Stem, Number
 and Length of Shoots from the Shoots.*

Nos.	No. of Sgs.	Average height in cm.			Average length of laterals, Nov. 1931.	Average girth of stem in cm.		Average number of stocks per stool, Nov. 1932.	Average total length of stocks per stool, Nov. 1932.	Average length per stock, Nov. 1932.	Average total length of laterals per stool, Nov. 1932.
		Average height in cm.				Average girth of stem in cm.					
		Aug. 1930.	Feb. 1931.	Nov. 1931.		Feb. 1931.	Nov. 1931.				
I × IX	71	18.0	27.0	47.3	44.9	0.50	0.73	2.67	186.1	69.4	96.7
IX × I	76	22.8	33.9	51.2	48.4	0.56	0.76	2.93	200.9	68.5	90.5
II × IX	40	37.7	48.7	69.4	78.9	0.64	0.95	2.85	206.3	72.4	195.1
IX × II	7	42.2	51.8	69.6	55.9	0.70	0.94	3.29	197.7	60.2	87.1
IV × IX	100	29.4	36.6	59.8	102.3	0.57	0.97	4.32	288.0	66.7	150.5
IX × IV	53	27.4	34.5	63.7	99.1	0.57	1.01	4.65	318.5	68.4	109.4
V × IX	49	47.4	56.0	70.5	146.5	0.71	1.18	5.06	350.6	65.1	177.3
IX × V	16	46.4	56.6	81.3	143.2	0.68	1.30	4.69	319.9	68.4	60.7
VI × IX	75	38.7	47.5	69.0	90.7	0.60	1.02	3.20	215.5	62.5	99.2
IX × VI	109	37.0	46.1	67.5	117.9	0.60	1.09	3.71	269.9	72.7	189.2
VII × IX	56	34.5	40.4	67.6	91.5	0.59	1.01	3.23	223.8	69.2	45.8
IX × VII	69	37.9	43.8	52.2	64.4	0.59	0.87	2.41	149.1	61.9	28.8
IX × IX	10	33.0	38.8	60.4	58.3	0.59	0.91	2.89	204.5	70.8	114.2
IX × XII	5	31.5	39.8	58.2	76.8	0.56	1.03	4.50	288.5	64.1	147.0
IX × XIII	16	41.5	52.1	71.1	65.6	0.62	0.84	2.50	193.5	77.6	136.4
IX × XIV	23	30.8	43.1	60.4	45.0	0.56	0.88	3.00	198.2	66.1	64.9
IX × XV	66	40.6	42.1	61.4	74.7	0.58	0.94	3.11	205.0	65.8	133.9
IX × XVI	34	37.7	40.5	56.2	62.5	0.57	0.86	2.32	136.4	58.7	57.5
IX × XVII	40	31.5	33.8	52.4	48.3	0.54	0.90	2.86	167.9	58.7	34.2

VIGOUR AS EXPRESSED BY WOOD GROWTH.

Records of the vigour of the seedlings were taken during the late Summer of 1930, and during the Winters of 1930, 1931 and 1932. They took the form of measurements of length of wood growth and of diameter of the stems at two inches above soil level. Upon the stools the individual stocks were counted and measured but it was found to be impracticable to obtain a record of the diameters of the individual stems. These figures are summarized in Table II.

The seedling families were throughout planted in sequence from $I \times IX$ to $XVI \times IX$ and were not randomized in any way either as young seedlings in the frame or later in the open field. The possibility that soil differences may have exerted a differential influence on their vigour should therefore be borne in mind in considering the results.

It is interesting to notice, in the earlier years, the relatively greater vigour of the seedlings of families $II \times IX$, $V \times IX$ and their reciprocals and the poorer growth of the seedlings of the $I \times IX$ and $IX \times I$ families. Actually, the seedlings of the two crosses between V and IX were, on the average, more than twice the height of those of the two crosses between I and IX by August, 1930, and, while this difference had been diminished by November, 1931, it was still considerable. These differences may possibly be ascribable to delayed germination on the part of those families, such as $I \times IX$, $IV \times IX$ and their reciprocals, which had made outstandingly less growth in their first season than the remainder. As may be seen from Table II, there were considerable differences between the families of seedlings in the increments of growth made between February, 1931 and November, 1931. Seedlings of the two crosses $I \times IX$ and $IX \times I$ increased in height, on the average, by 75 and 53 per cent. respectively, between those two dates, while those of $V \times IX$ and $IX \times V$ increased in height, on the average, by 26 and 44 per cent. respectively. The two families, $IV \times IX$ and $IX \times IV$, which, with the exception of $I \times IX$ and its reciprocal, were, on the average, shorter than any other family in February, 1931, increased in height by 63 and 85 per cent. respectively, while $II \times IX$ and its reciprocal only increased in height by 42 and 34 per cent. respectively.

Measurements of the diameter of the stems of the seedlings were taken on two occasions and are summarized in Table II. Of all the families, the crosses between II and IX and V and IX had the greatest average stem diameter by February, 1931. There was comparatively little difference between the remaining fifteen families except in the case of $I \times IX$, in which the seedlings were, on the average, appreciably more slender than those of any other family. At the end of the following season the seedlings of $V \times IX$ and its reciprocal were outstandingly stouter, on the average, than those of any other family, but those of $II \times IX$ and $IX \times II$ had actually been outstripped by seven of the remaining fifteen families. The two families, $I \times IX$ and $IX \times I$, whose average stem

diameters were 84 per cent. and 94 per cent. that of the average of all the families taken together, in February, 1931, had fallen to 76 per cent. and 79 per cent. respectively by November, 1931. These figures suggest that there were considerable differences in the increment of stem diameter made by the respective families between those two dates and a comparison of the figures in Table II will show that this was actually the case. Thus, whereas the two crosses between V and IX showed an average increase in stem diameter, during the season, of 66 per cent. and 91 per cent. respectively, and those between IV and IX 70 per cent. and 77 per cent. respectively, the average increase in the case of the two families between I and IX was only 46 per cent. and 36 per cent. respectively, while in the case of the two families between II and IX it was 48 per cent. and 34 per cent. respectively. These figures show little correspondence with those for increase in length of stem during the same period but do appear to be correlated with the quantity of lateral growths or side shoots developed during the year.

While the averages of stem diameter give a picture of the general differences between the respective families with regard to this character, it will be of interest to consider in greater detail the proportion of the seedlings which would have been fit for working with a scion variety at the end of their first and second seasons. In Table III the percentage of the seedlings in each family, fit to be worked during the Winters of 1930 and 1931 are tabulated. Obviously the diameter of the stem is the really important consideration, mechanically, in deciding whether a stock is fit to work or not and, in practice, a diameter of .6 cm. or the thickness of the average lead pencil, would probably be the approximate dividing line in separating those stocks which were "workable" from those which it was not possible to work. A stem diameter of .6 cm. has, therefore, been made the limit in classifying the seedlings for the purposes of Table III. As may be seen, more than 80 per cent. of the seedlings in families V $\times$ IX and IX $\times$ V were fit for working at the end of their first season, while nine of the remaining families had fewer than 50 per cent. workable stocks. I $\times$ IX was outstandingly the poorest family with only 17 per cent. of workable seedlings at the end of their first season. By the end of their second season a considerably larger proportion were fit for working. In thirteen of the families over 90 per cent. of the seedlings would have been fit to work, while in the poorest families, I $\times$ IX, IX $\times$ I, IX $\times$ XV and XVI $\times$ IX, over 70 per cent. of the seedlings had exceeded in diameter the limit assigned. Upon the other hand, it must be borne in mind that these seedlings received much more careful treatment and were grown under much better conditions than is the case with plantations of seedling stocks sown for nursery purposes and the fact that four of the nineteen families considered here failed to produce 80 per cent. of workable rootstocks by the end of their second season, with such advantages, is

TABLE III.

Percentage of Seedlings fit to work at One and Two Years Old and Percentage of Clean, Slightly and Much "Feathered" Seedlings at Two and Three Years Old.

	Sdgs. 6 mm. or more diam. Feb., 1931.	Sdgs. 6 mm. or more diam. Nov., 1931.	Number of Lateral "Feathers".					
			Clean.	6 or less.	6 or more.	Clean.	6 or less.	6 or more.
			Nov., 1931.	Nov., 1931.	Nov., 1931.	Nov., 1932.	Nov., 1932.	Nov., 1932.
	%	%	%	%	%	%	%	%
I × IX	17.4	71.0	4.5	85.1	10.4	27.5	53.6	18.9
IX × I	42.1	78.3	4.2	86.1	9.7	37.0	52.0	11.0
II × IX	62.5	90.0	2.5	67.5	30.0	15.0	30.0	55.0
IX × II	85.7*	100.0	0	71.4	28.6	0	83.3	16.7
IV × IX	45.0	93.8	5.2	51.5	43.3	20.0	57.9	22.1
IX × IV	41.5	98.1	5.5	55.5	39.0	17.3	65.4	17.3
V × IX	83.3	93.8	6.1	36.8	57.1	18.8	60.4	20.8
IX × V	81.2*	100.0	6.2	31.3	62.5	37.5	56.3	6.2
VI × IX	49.3	94.4	2.7	51.3	46.0	20.5	49.3	30.2
IX × VI	53.2	92.6	3.7	47.7	48.6	17.7	42.1	40.2
VII × IX	48.2	94.4	1.9	64.8	33.3	36.5	55.7	7.8
IX × VII	47.2	90.2	3.2	61.8	35.0	49.2	44.2	6.6
XII × IX	60.0*	88.9	20.0	20.0	60.0	11.1	22.2	66.6
IX × XII	60.0*	100.0	0	75.0	25.0	25.0	25.0	50.0
XIII × IX	62.5*	86.7	20.0	26.7	53.3	14.3	21.4	64.3
IX × XIII	54.5	100.0	4.5	59.1	36.4	31.8	50.0	18.2
XV × IX	43.9	92.2	4.6	47.7	47.7	14.7	44.3	41.0
IX × XV	55.9	79.4	8.8	61.8	29.4	35.3	41.2	23.5
XVI × IX	35.0	77.4	15.6	53.1	32.3	37.9	44.8	17.3

* There were fewer than 20 seedlings in these families.

an indication that they would have proved most unsatisfactory had they been subjected to the more stringent conditions of the ordinary nursery seedling beds.

Of the records taken upon the seedlings during the Winter following that in which they were cut down and stooled probably the most interesting are those relating to the average number of shoots produced per stool (see Table II). As may be seen there were wide variations between the families in the average number of shoots produced by each stool. Families with an outstandingly high shoot production were IV × IX, IX × IV, V × IX and IX × V, in which an average of between four and five shoots were produced per stool. Families I × IX, IX × I, II × IX, IX × VII, XII × IX, XIII × IX, IX × XV and XVI × IX, on the other hand, gave a much lower average number of shoots per stool, fewer than three in each case. The number of shoots obtained from the individual stools are analysed in detail in Table IV. The seedlings are classified according to the amount of rooting on the shoots in order that any

possible correlation between the quantity of shoots produced by each stool and the extent of their rooting may be disclosed. Of all the crosses, probably those between IV and IX and V and IX gave the largest proportion of stools of high shoot production. Thus, in family IV $\times$ IX, 45 per cent. of the seedlings produced five or more shoots per stool, in family IX $\times$ IV, 48 per cent. and in family V $\times$ IX 54 per cent. On the other hand, families I $\times$ IX, IX $\times$ I, VII $\times$ IX and IX $\times$ VII were particularly poor in this respect, having only 7, 14, 17 and 5 per cent. respectively of seedlings with five or more shoots per stool.

TABLE IV.

Analysis of Number of Stocks per Stool classified according to Quality of Rooting.

No. of Stocks.	Well or Moderately Rooted.							Poorly Rooted or Not Rooted.						
	I4-13	I2-11	10-9	8-7	6-5	4-3	2-1	I4-13	I2-11	10-9	8-7	6-5	4-3	2-1
I $\times$ IX	0	0	0	0	4	25	12	0	0	0	0	1	8	19
IX $\times$ I	0	0	0	1	8	23	13	0	0	0	0	1	6	21
II $\times$ IX	0	0	0	1	4	12	14	0	0	0	0	1	1	7
IX $\times$ II	0	0	0	0	2	1	2	0	0	0	0	0	2	0
IV $\times$ IX	0	0	1	7	33	34	6	0	0	0	1	1	5	7
IX $\times$ IV	0	1	1	2	14	18	2	0	0	0	0	7	5	2
V $\times$ IX	0	0	6	4	14	12	6	0	0	0	1	1	4	0
IX $\times$ V	1	0	0	2	2	6	1	0	0	0	0	0	3	1
VI $\times$ IX	0	0	0	2	8	25	12	0	0	0	0	1	9	16
IX $\times$ VI	1	0	3	5	14	40	19	0	0	0	1	1	11	12
VII $\times$ IX	0	0	0	1	5	22	11	0	0	0	0	3	3	7
IX $\times$ VII	0	0	0	1	1	18	19	0	0	0	0	1	6	15
XII $\times$ IX	0	0	0	0	1	2	2	0	0	0	0	0	1	3
IX $\times$ XII	0	0	0	0	2	1	1	0	0	0	0	0	0	0
XIII $\times$ IX	0	0	0	0	0	4	4	0	0	0	0	0	2	4
IX $\times$ XIII	0	0	0	0	1	11	3	0	0	0	0	0	3	4
XV $\times$ IX	0	0	0	1	6	25	19	0	0	0	0	2	4	4
IX $\times$ XV	0	0	0	0	1	12	10	0	0	0	0	0	1	11
XVI $\times$ IX	0	0	0	1	3	4	4	0	0	0	0	2	2	13

From the figures given in Table IV it appears fairly evident that there is little correlation between the number of shoots produced per stool and the extent to which they were rooted. Such evidence as Table IV affords appears to lend support to the view that the stools with poorly rooted shoots had, in general, a smaller number of shoots per stool than was the case with stools whose shoots were better rooted. For instance, of 41 stools with well or moderately well rooted shoots in family I $\times$ IX, 12, or 29 per cent. had two or fewer shoots per stool while, of 28 stools with poorly rooted or unrooted shoots, 19, or 68 per cent. had two or fewer shoots per stool. Again, in family IV $\times$ IX, of 81 stools with well or moderately well rooted shoots, 6, or 7 per cent. had two or fewer shoots per stool, while, of 14 stools with shoots poorly rooted or not rooted at all, 7, or 50 per cent. had not more than two shoots per stool.

With regard to the average length of the shoots produced by the stools in the different families, shown in Table II, those of family XIII $\times$ IX appear to have been considerably the longest and those of IX $\times$ XV and XVI $\times$ IX the shortest. Other families with stools whose shoots appear to have been longer than the average were II $\times$ IX, IX $\times$ VI and XII $\times$ IX. Families I $\times$ IX, and IX $\times$ I, which, in the two Winters prior to stooling, had been, on the average, shorter than any other family, had produced by the first Winter following stooling a larger aggregate length of shoot per stool, on the average, than families IX $\times$ VII, IX $\times$ XV and XVI $\times$ IX, and were only very slightly inferior in this respect, to families IX $\times$ II, XII $\times$ IX, XIII $\times$ IX, IX $\times$ XIII and XV $\times$ IX. Obviously, within reasonable limits, the length of the shoots produced by the stools is of less practical importance than their stoutness for the purposes of working them. While it was not practicable to obtain exact measurements of the diameter of the stems of the individual shoots, observations made by eye, suggested that there was a proportion of the stools in each family which had shoots which were more slender and whippy than the remainder. The proportions found in the different families showed considerable variation although stools with stoutish shoots predominated in every family.

Lateral growths appeared upon the stems of the seedlings in their second year and again, on the shoots arising from the stools. They varied from short, sharp spines of less than one centimetre long to whippy shoots of considerable length. Very wide differences occurred too, from seedling to seedling in the number of such growths which they developed. The occurrence of these lateral growths is thought to be associated with a "juvenile" condition in the seedlings (20). With regard to the length of the lateral growths as recorded in the Winter of 1931, the crosses between IV and IX and V and IX had outstandingly the greatest average total, while I $\times$ IX and XVI $\times$ IX had considerably the least. Upon the shoots, recorded during the Winter of 1932, the figures are much more variable, differences between two crosses between the same varieties being often extremely great. It is probable that the differences in average length of lateral growths which occur are not significant, except, possibly, in the case of the crosses between VII and IX and XVI and IX, which show a markedly lower average total of such lateral wood.

These side shoots, if present on apple stocks in large numbers are a decided drawback since, if left, they make the stocks difficult to work, while their removal requires considerable time and labour. In Table III, the seedlings have been classified according to the number of laterals which they developed in the seasons 1931 and 1932. No account could be taken of the position of the laterals on the shoots but those with six or fewer laterals are separated from those with more than six, it being considered that a greater number than six laterals per shoot would probably seriously interfere with their efficiency as rootstocks.

At the end of 1931 there was a small percentage, rarely amounting to more than 10 per cent., of the seedlings which were completely devoid of laterals. In only four of the nineteen families, however, were there more than 50 per cent. of the seedlings with more than six lateral growths each. The two families between I and IX had an outstandingly large proportion of stocks with six or fewer laterals while those between V and IX had a relatively small proportion of such seedlings. At the recording at the end of 1932 there was a much larger percentage of stools whose shoots were clean, amounting, in the case of family IX $\times$ VII to almost 50 per cent. and being, in no case, lower than 10 per cent. On the other hand, if the families with fewer than twenty members be excluded, in only one instance, family II $\times$ IX, was there an average of more than six laterals per shoot on more than 50 per cent. of the seedlings. Family V $\times$ IX, which in the previous year had had a large proportion of seedlings with six or more laterals each, had, in 1932, on the average, over 80 per cent. of stools with shoots either with no feathers at all or with an average of fewer than six feathers per shoot.

CHARACTERS OF THE SHOOTS.

Detailed records were made of a number of botanical characters both on the seedlings during their first season and also upon the shoots arising from the stools. In making these records it was not merely hoped that some light might be shed upon the mode of inheritance of characters in these apple seedlings, but also that, in this way, correlations might be established between botanical characters distinguishable during the earlier years of the seedlings' life and such attributes of economic importance as ease of multiplication by vegetative means or some desirable influence over the scion variety. It may take fifteen years or more for a potential new rootstock to pass from the condition of an apple pip to that of a fully tested new variety of recognized commercial utility and if it could be demonstrated that the factors governing such a complex of desired characters were correlated or linked in inheritance with certain clearly defined and easily recognizable morphological characters in the young seedlings, a considerable short circuiting of the present laborious and protracted methods of testing would be possible.

(a) *Wood Colour.*

The seedlings varied widely in the precise colour of their wood from a smoky purple-brown to a bright reddish-brown. In each family a proportion of seedlings with reddish-brown wood occurred, although families IV $\times$ IX and IX $\times$ IV contained the largest proportion. A variable number of seedlings in most families were tinged green towards their base. In families VI $\times$ IX and

IX $\times$ VI this green coloration occurred on all the seedlings and, in many cases extended throughout the whole length of the shoots.

(b) *Lenticels—Size and Number.*

Observations on the size and number of the lenticels on the wood of the seedlings, taken during three seasons, showed little evidence of a definite, clear cut, segregation for these characters. A number of seedlings were described on each occasion as having larger lenticels than the remainder and a number occurred in which they were more numerous, but the classes showed a considerable degree of intergradation. With the possible exception of the two families, V $\times$ IX and IX $\times$ V, which were noted as having a somewhat larger proportion of seedlings with large lenticels, it seems probable that the seedlings were varying in a continuous manner between similar extremes.

(c) *Buds—Size and Colour.*

Little difference could be observed with regard to the size of the buds either on the seedlings or upon the shoots from the stools. A small proportion were distinguished as having somewhat larger buds than the rest during the Winter of 1930 but, upon the stools, all were described as being of uniform size. In colour, however, the buds of the seedlings showed considerable variation. At the 1930 observation a distinction could be made between seedlings whose buds were of a bright pink or carmine colour and those with buds of a dull, dark red. With the exception of families IV $\times$ IX, IX $\times$ IV, V $\times$ IX and IX $\times$ V, in which the two classes occurred in approximate equality, seedlings with bright pink buds predominated to a greater or less extent. The precise ratios showed wide variation, however, and do not suggest that there was any very definite segregation for this character. During the Winter of 1932 the chief contrast to be observed was that between seedlings with buds of a pale grey appearance and those showing a variable amount of red on their surfaces. This coloration varied considerably in its intensity from a dull purple to a bright carmine and also in the amount of the bud coloured. Families V $\times$ IX and IX $\times$ V had a considerably larger proportion of seedlings with coloured buds. In all the other families seedlings with greyish buds preponderated over those with coloured buds. The individual ratios varied widely.

(d) *Size of the Leaves.*

The relative size of the leaves of the seedlings was recorded during the Summer of 1930 when they were less than one year old and again upon the shoots from the stools during the Summer of 1932. An idea of the extreme differences in the size of the leaves upon different seedlings may be obtained from Fig. 1. Actually, very wide variations were found among leaves from the

same seedling or among shoots from the same stool and although an attempt was made to classify them there can be little doubt that the variations observed were not of a sharply discontinuous nature.

(e) *Shape of the Leaves.*

In recording this character both upon the young seedlings and the stool-shoots wide variations were found between leaves upon the same individual and while there were indications that a larger proportion of the seedlings in families $I \times IX$, $IX \times I$, $IV \times IX$ and $IX \times IV$ had, upon the whole, broadish leaves than was the case in the remaining families, no evidence of a definite discontinuous segregation could be found. The range of variation in leaf shape among these seedlings is illustrated in Fig. 1.

(f) *Colour of the Leaves.*

The majority of the seedlings in their first year were recorded as having dark green leaves. Upon the shoots from the stools individuals with medium green leaves preponderated in most families. There can be no doubt that the colour of the leaves was influenced to a large extent by environmental conditions and since the differences observed were not particularly great, it is doubtful whether the ratios observed have any significance.

(g) *Leaf Apex.*

This character was only recorded upon one occasion, on the young seedlings in 1930. Certain families such as $II \times IX$, $V \times IX$, $VI \times IX$, $VII \times IX$ and their reciprocals occurred in which practically all the seedlings had acute leaf apices. In the remaining families, while individuals with acute leaf apices were in the majority, a variable proportion of seedlings with obtuse leaf apices occurred.

(h) *Serrations of the Leaf Margin.*

At the earlier observation, in 1930, on the seedlings at less than a year old, individuals with acutely serrate leaf margins were found to preponderate although the proportions found were variable. At the observation made in 1932 on the shoots from the stools, however, seedlings with obtuse leaf serrations were in the majority. In certain families, such as $I \times IX$, $V \times IX$, $VI \times IX$, $XIII \times IX$, $XV \times IX$, their reciprocals, and $XVI \times IX$, the proportion of seedlings with obtusely to those with acutely serrate leaf margins was considerably lower than was the case in the remaining families but the ratio of the two classes to one another in the individual families showed considerable variation.

(i) *Pose of the Leaves.*

On the young shoots from the stools two fairly distinct classes could be discriminated with respect to the pose of the leaves. The larger part of most

of the families had leaves held somewhat laxly, the whole leaf, lamina and petiole, being curved over and forming together almost a semi-circle with the apex of the leaf pointing downwards. In the other class the leaves were definitely upturned, petiole and lamina being held more or less in one straight line, and pointing upwards (see Fig. 2). These differences were most clearly seen in the leaves towards the upper part of the shoots. With the exception of $\text{XIII} \times \text{IX}$ and its reciprocal in which seedlings with upturned leaves occurred exclusively, individuals with curved over leaves were in the majority in most of the remaining families. The two classes occurred in approximate equality, however, in families $\text{II} \times \text{IX}$, $\text{IV} \times \text{IX}$, $\text{VII} \times \text{IX}$ and their reciprocals while in family $\text{XVI} \times \text{IX}$ seedlings with upturned leaves preponderated. Of the rootstocks used as parents in these crosses, Nos. IV, VII, XIII and XVI were noted by Hatton as having erect leaves in clonal races.

(j) *Leaf Petiole—Size and Colour.*

The seedlings were classified on the length¹ and colour of the leaf petiole both in 1930 and in 1932. Among the young seedlings there was a considerable preponderance of individuals with short petioles. The observations upon the shoots from the stools showed that there was great variability among the families for this character. In general, however, in families $\text{I} \times \text{IX}$, $\text{IV} \times \text{IX}$, $\text{VII} \times \text{IX}$ and their reciprocals seedlings with longish petioles predominated, in families $\text{V} \times \text{IX}$, and $\text{IX} \times \text{V}$ the two classes occurred in approximate equality while in the remaining families individuals with short petioles predominated. Hatton described the leaf petioles of Nos. IV and VII as long, those of Nos. XIII, XV and XVI as short and those of the remainder of the rootstocks used in these experiments as of intermediate length. Observations on the colour of the petioles of the shoots from the stools showed considerable differences between the families for this character. Families $\text{XIII} \times \text{IX}$ and $\text{IX} \times \text{XIII}$ had exclusively seedlings with very bright crimson leaf petioles. In families $\text{II} \times \text{IX}$, $\text{IV} \times \text{IX}$, $\text{V} \times \text{IX}$, $\text{VII} \times \text{IX}$, $\text{XII} \times \text{IX}$, $\text{XV} \times \text{IX}$, their reciprocals and $\text{XVI} \times \text{IX}$, the majority of the seedlings had bright crimson petioles but in the remaining families the proportion of such seedlings was much lower, the greater number being less intensely coloured.

(k) *Stipules—Size and Shape.*

These seedlings showed variation both in the size and the shape of the stipules at the base of the leaf petioles. They could, however, be approximately classified on the size of the stipules although, in shape, they showed considerable variation between long and narrow (lanceolate) stipules and those which were much broader in proportion to their length (elliptical). Both in 1930 and 1932, in all families, seedlings with small stipules and those with narrow (lanceolate)

TABLE V.
Illustrating Resemblances and Differences between the Seedlings and their Parents.

No. of Stock.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	(a)	(b)
I × IX	19	0	0	0	0	1	1	0	21	0	0	0	0	0	0	0	20	1
IX × I	13	0	0	0	0	1	0	0	25	0	0	0	0	0	0	0	30	4
II × IX	3	13	0	0	0	1	0	0	5	0	0	0	0	0	0	0	15	3
IX × II	1	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0
IV × IX	0	0	0	32	0	1	1	0	24	0	0	0	0	0	0	0	34	3
IX × IV	0	0	0	14	0	0	0	0	10	0	0	0	0	0	0	0	17	5
V × IX	0	0	0	0	28	0	0	0	1	0	0	0	0	0	0	0	14	3
IX × V	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	9	1
VI × IX	1	0	0	0	0	40	0	0	3	0	0	0	0	0	0	0	26	1
IX × VI	2	0	0	0	0	53	0	0	3	0	0	0	0	0	0	0	43	3
VII × IX	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	16	3
IX × VII	0	0	0	0	0	0	26	0	10	0	0	0	0	0	0	0	27	1
IX × IX	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	1	1
XII × IX	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	1	0
IX × XII	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4
XIII × IX	0	0	0	0	0	0	0	0	0	0	0	1	7	0	0	0	9	1
IX × XIII	0	0	0	0	0	0	0	0	2	0	0	1	11	0	0	0	22	3
XV × IX	0	0	0	0	0	0	0	0	1	3	0	1	0	0	28	0	0	0
IX × XV	0	0	0	0	0	0	0	0	1	0	0	0	0	0	16	0	10	0
XVI × IX	0	0	0	0	0	0	5	0	2	4	0	0	0	0	1	11	6	1

Column (a). Seedlings intermediate between their two parents.

Column (b). Seedlings which did not resemble any known member of the Paradise Apple Rootstock Series.

stipules were in the majority except in families $I \times IX$ and $IX \times I$ in which, in 1932, there was a very slight preponderance of seedlings with large stipules. The ratios in the individual families varied within very wide limits.

(l) *General Characters.*

It must be borne in mind that each of the varieties of rootstocks possesses an individuality of its own which to a large extent transcends the more obvious morphological differences such as those dealt with above. In spite of the wide variations which have been found to exist in the seedling rootstocks dealt with here it was still possible, to a limited extent, to pass along the rows and identify the parents from the seedlings. In Table V are tabulated the results of such an examination made on the stooled seedlings during the Summer of 1932, by Messrs. J. Amos and A. W. Witt.* Both these workers have had a wide practical experience in the identification of the "Paradise" Apple Rootstocks. They confined themselves strictly to the broad question of whether the seedlings resembled most closely their father or their mother or whether both were represented in approximately equal degrees.

It is interesting to notice that in the case of no cross do the characters of one or other of the two parents preponderate to the complete exclusion of the other although in certain cases, notably $XIII \times IX$ and $IX \times XIII$, seedlings closely resembling No. IX did not occur. There were numerous instances where seedlings unlike either of their parents but similar to some other member of the Paradise series were recorded and, in 41 cases, seedlings were observed which did not approximate to any member of the Malling series.

(m) *Disease.*

A few of these seedlings were recorded as having been infested with apple mildew during the Summer of 1930. During the Summer of 1931 the attack was somewhat more severe, more than 50 per cent. of the seedlings being mildewed in certain families. At the same time a very severe attack of apple scab was observed both on the leaves and on the wood of the seedlings. Detailed records of the incidence of these troubles in the different families were made by Mr. M. H. Moore of the Mycological Section.† With regard to the incidence of apple mildew, while the proportion of seedlings infested varied widely in the different families little indication could be observed of crosses outstandingly more or less susceptible to the trouble. In the case of apple scab, on the other hand, while most of the families were very severely attacked, there having been very few individuals in any cross entirely free from the disease, while, in most cases well

* The writer takes this opportunity of acknowledging the collaboration of these two colleagues in this section of the work.

† The writer is indebted to Mr. Moore for permission to discuss his data here.

over 25 per cent. were severely attacked, the two crosses between Nos. IV and IX showed a very high degree of resistance, well over 50 per cent. being completely clean in each case and fewer than 5 per cent. severely infested. The trouble did not recur to any serious extent upon the shoots arising from the stools during 1932.

CHARACTERS OF THE ROOTS.

Characters of the Roots of the Young Seedlings.

During the Winter of 1930, the seedlings, then about one year old, were lifted for transfer from their temporary nursery quarters to the beds in which they were to be stooled. The opportunity was taken to subject their root systems to a critical examination. The main roots were found to have been somewhat distorted by their early restriction in pots. In very few cases was a single tap root found to have developed, as may be seen in Figs. 3, 4 and 5, the main framework consisting, in the generality of cases, of a variable number of more or less equally developed roots. Their general direction was not by any means invariably directly downwards. In spite of much distortion it was possible to observe systems which were much more spreading than the remainder. (Compare, for

TABLE VI.

Characters of the Root Systems of the One Year Old Seedlings.

	Size of the Roots.			Character of the Fibre.				Type of Collar Rooting.			
				In Upper Part.		Evenly distributed.					
	Large.	Med.	Small.	Much or mod.	Little.	Much or mod.	Little.	Coarse Roots.	Small Roots.	Only Fibre.	Little or no rooting
I × IX	8	22	40	36	17	12	5	6	46	14	3
IX × I	14	23	39	41	15	13	7	24	40	9	3
II × IX	7	13	19	16	10	12	2	8	21	7	4
IX × II	3	2	2	6	0	1	0	3	1	3	0
IV × IX	17	29	54	52	14	26	8	23	47	24	6
IX × IV	10	11	32	26	11	13	3	9	27	12	5
V × IX	9	15	25	26	11	9	3	11	26	11	1
IX × V	4	5	7	7	4	4	1	2	10	3	1
VI × IX	13	17	45	46	10	13	6	19	42	11	3
IX × VI	13	31	65	53	22	27	7	16	62	21	10
VII × IX	14	15	26	31	5	16	4	4	33	12	7
IX × VII	7	20	42	34	12	19	4	8	39	19	3
XII × IX	1	5	4	5	3	2	0	0	4	4	2
IX × XII	0	2	3	3	1	1	0	0	2	2	1
XIII × IX	5	5	6	12	2	2	0	2	7	6	1
IX × XIII	6	7	10	16	4	3	0	2	12	6	3
XV × IX	5	18	43	38	11	13	4	9	42	12	3
IX × XV	1	7	26	19	5	9	1	6	20	5	3
XVI × IX	2	16	22	27	7	4	2	2	24	11	3

instance, the first and last seedlings in Fig. 4.) The results of detailed observations upon these seedlings are tabulated in Table VI.

(a) *Size of the Main Roots.*

The seedlings were classified by eye on the size of the main roots. There was found to be a considerable preponderance in every family of seedlings with small roots. For an illustration of the size differences found, see Fig. 3.

(b) *Amount and Distribution of the Fibre.*

The fibre borne on the root systems varied both in quantity and in the position which it occupied on the root system. Upon the amount of the fibre present it was possible to divide the seedlings into two groups, those having much or a moderate quantity of fibre and those in which the fibre was sparse. On the distribution of the fibre, too, the seedlings were divisible into two broad classes, those in which the fibre was almost exclusively confined to the upper part of the root system and those in which it was evenly distributed throughout the whole system (see Fig. 4). These classes were fairly distinct and well defined and, although some overlapping occurred, they could usually be discriminated without much difficulty.

(c) *Type of Collar Rooting.*

The seedlings were recorded on the character of such collar roots as were present. Four main classes could be discriminated. The majority of the seedlings had small but well defined roots with a variable amount of fibre. A second class could be recognised in which the roots were coarsish in character and a third in which only fibre was present at the collar. Finally, a small class occurred in which there were no roots present upon the collar at all. In general the class limits could be set with moderate exactitude with the possible exception of that between large and small roots. In this case there was undoubtedly considerable intergradation.

CHARACTERS OF THE ROOTS OF THE STOOL-SHOOTS.

The characters of the root systems of the shoots from the stooled seedlings were recorded during the Winter of 1932. The records are summarised in Table VII. As might have been expected, the adventitious systems evolved on such young shoots were much more difficult to classify than the root systems of mature trees would have been and the results obtained can only be regarded as approximations.

(a) *Amount of Rooting.*

The relative quantity of roots produced by the seedlings was recorded. The figures shown in Table VII do not suggest that any particular combination

TABLE VII.

Characters of the Root Systems of the Stool-Shoots.

	Type of Main Roots.			Total Amount of Root.		Amount of Fibre.		Type of Collar Rooting.			Height of the Roots.					
	Small Roots.	Coarse Roots.	Fibre only.	No rooting.	Much.	Moderate.	Little.	Much.	Moderate.	Little.	Small Roots.	Fibre only.	No rooting.	High.	Med.	Low.
I x IX	40	12	13	4	12	29	28	2	18	49	46	10	13	20	32	17
IX x I	47	10	14	2	18	27	28	7	28	38	53	15	5	41	24	8
II x IX	25	7	6	2	8	23	9	6	19	15	29	8	3	19	17	4
IX x II	5	1	1	0	2	4	1	1	3	3	5	2	0	3	3	1
IV x IX	63	9	20	3	39	42	14	31	48	16	60	30	5	49	39	7
IX x IV	32	9	7	4	13	25	14	14	22	16	33	13	6	18	28	6
V x IX	28	11	7	2	16	26	6	8	31	9	35	11	2	25	19	4
IX x V	11	2	3	0	3	9	4	3	8	5	14	2	0	9	6	1
VI x IX	44	11	11	7	12	35	26	0	37	36	49	16	8	37	25	11
IX x VI	70	17	14	6	19	63	25	16	52	39	69	31	7	53	44	10
VII x IX	33	10	8	1	9	30	13	7	22	23	35	13	4	16	28	8
IX x VII	43	4	10	4	5	34	22	4	29	28	35	17	9	25	19	16
IX x IX	4	0	4	1	2	3	4	2	2	5	3	3	3	2	4	4
IX x X	4	0	0	0	0	4	6	0	4	0	3	1	0	4	0	0
IX x XII	4	0	0	0	0	6	7	1	4	8	6	6	2	7	3	4
XIII x IX	6	3	4	1	2	13	7	1	10	11	12	9	1	9	11	2
IX x XIII	13	6	3	0	2	13	33	15	33	13	37	21	3	28	26	7
XV x IX	43	10	7	1	16	34	11	15	16	14	13	14	7	7	15	12
IX x XV	18	3	10	3	2	21	11	4	16	14	16	14	7	6	14	9
XVI x IX	15	6	7	1	2	10	17	2	9	18	6	16	7			

of parents gave a significantly larger proportion of seedlings with well rooted shoots than any other. The three classes into which the seedlings were divided are illustrated in Fig. 6.

(b) Character of the Main Root.

The seedlings were found to be divisible into four main classes upon the type of main roots which were developed upon the stool-shoots. Among those which had developed well defined roots at all, the large proportion had roots which were described as small and which, while they varied widely, were, on the average, of about the thickness of a piece of twine, while in the remainder larger roots of a coarser texture had been developed. Finally, two further classes were discriminated, those in which the system consisted entirely of fibrous roots and those in which there was no rooting at all. There can be little doubt that these differences in root character were closely related to the length of time during which the roots had been formed. The classes were not, in every case, sharply discontinuous nor did the different shoots upon the same stool always show uniformity in the type of root system which they possessed.

(c) Amount of Fibre on the Main Root System.

The relative quantity of fibre present on the root systems of the shoots from the stools was recorded. As might be expected, the families varied widely, differences between reciprocals often being extremely great. In general, however, it is probably fairly safe to say, that a larger proportion of the seedlings in families IV $\times$ IX, V $\times$ IX, XII $\times$ IX, XV $\times$ IX and their reciprocals bore shoots which were well fibred than was the case in the remaining families.

(d) Type of Collar Rooting.

The majority of the shoots from the stools bore roots at varying distances above the main root aggregates which corresponded very approximately with the collar root systems of the young seedlings. As may be seen from Table VII, it was possible to classify the seedlings into three groups on the type of such collar rooting exhibited by the shoots from the stools. The larger class had well differentiated roots of varying size but more or less approximating, in general, to what has been described as small root in recording the main root systems. A second class consisted of those seedlings whose shoots had only fibre at the collar. Finally, there was a small class, corresponding closely to the class which had no rooting at all on the shoots, in which collar roots were completely absent. While much variation occurred among the shoots from the same stool and the results for the different families vary within wide limits, it is probably correct to say that families I $\times$ IX, II $\times$ IX, V $\times$ IX, VI $\times$ IX, VII $\times$ IX and their reciprocals contained a larger proportion of seedlings whose

shoots had well defined roots at the collar and a smaller proportion whose shoots had no rooting at the collar than was the case in the remaining families.

(e) *Height of the Roots.*

Wide differences were observed in the height to which the rooting extended up the stems of the stool-shoots. This varied somewhat from shoot to shoot upon the same stool but was sufficiently uniform to make it possible to allocate the seedlings into one of three classes (see Table VII). The ratios show extensive variation from family to family and the differences are probably to a large extent fortuitous.

DISCUSSION.

In any scheme of systematic breeding work an intimate knowledge of the potentialities of the material available for use is of paramount importance. Such a knowledge can only be obtained from an extended study of the results of breeding experiments with such material. In dealing with plants of great apparent genetic complexity, such as varieties of the apple, it may well be that the closest study will fail to reveal the exact principles underlying the inheritance of characters and that any predictions as to the probable results of interbreeding with such varieties will have to be based on broader and more empirical lines.

Close observation on the seedling families dealt with in this paper has shown very clearly that certain combinations of rootstocks have given a higher proportion of vigorous seedlings, that certain others have given a relatively larger number of seedlings of high stock production on the stools or that, in still others, the seedlings or stocks were less thickly "feathered". While it is not, at the moment, possible to assign these differences with precision to any particular cause, there seems little reason to doubt that they were in origin, genetic.

While the attempt to simplify the work of testing these seedling rootstocks by relating their later performance to certain, easily recognizable, morphological characters in the young seedlings, is an obvious preliminary to the serious work of raising improved races of rootstocks and might well have proved outstandingly successful with a plant of simpler genetic constitution, an essential condition of its practicability must be the occurrence of sharply discontinuous characters. The most careful observations, during three seasons, on twenty-eight different shoot or root characters on these nineteen families of seedlings failed to reveal a single case in which it could be conscientiously said that a greater or lesser amount of intergrading between the classes did not occur and it is probable that this lack of discontinuity is due to the polyploid constitution of the apple. Of all the observations dealt with probably those relating to the pose of the leaves on the shoots from the stools and to the amount and distribution of the fibre on

the root systems of the one year old seedlings showed a higher degree of discontinuity than the remainder but even with these it cannot be pretended that the severance between the classes was absolute and complete.

Upon the other hand, it must not be forgotten that the crosses studied here were not particularly representative since they all had a common parent in No. IX. Other combinations might conceivably give rise to a wider range of variation or reveal further, more discontinuous, classes for some of the characters studied.

The writer desires to place on record his appreciation of the encouragement and advice of Mr. M. B. Crane, of the John Innes Horticultural Institution, extended to him throughout the course of this work.

SUMMARY.

This paper summarizes observations made during 1930, 1931 and 1932, on seedlings from crosses between varieties of the "Paradise" Apple Rootstocks.

Data illustrating the intercompatibility of the varieties used and the relative germination of the seed are presented and discussed.

Detailed records with regard to the wood growth, girth and "feathering" of the seedlings are analysed and discussed. Data relating to the vigour and productivity of the stools are summarized.

Records of fifteen botanical characters both on the young seedlings and on the shoots from the stools are dealt with. The segregation of most of these characters in the seedlings is shown to be variable and not discontinuous.

The results of an analysis of the root characters both of the one year old seedlings and of the one year old shoots from the stools are tabulated and discussed.

The result of an attempt to analyse the seedlings on the basis of their resemblance to their parents is given.

The bearing of such studies on future practical rootstock breeding work is discussed.

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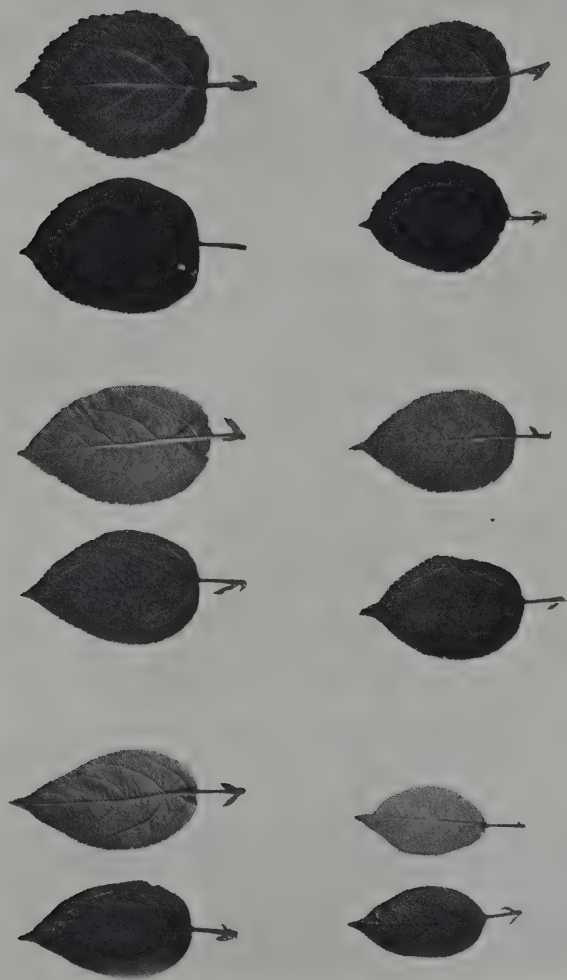


FIG. 1.
Illustrating variation in size and shape of the leaves on shoots from the stools.



FIG. 2.

Illustrating two types of leaf pose on shoots from the stools: (left) leaves curved over, (right) leaves upturned.



FIG. 3.

Illustrating variation in size of main roots on root systems of one year old seedlings :
(left) small roots, (centre) medium sized roots, (right) large roots.



FIG. 4.

Illustrating amount and distribution of fibre on root systems of one year old seedlings. Left to right, much fibre in upper part of system; sparse fibre in upper part of system; much fibre evenly distributed throughout the system, sparse fibre evenly distributed throughout the system.

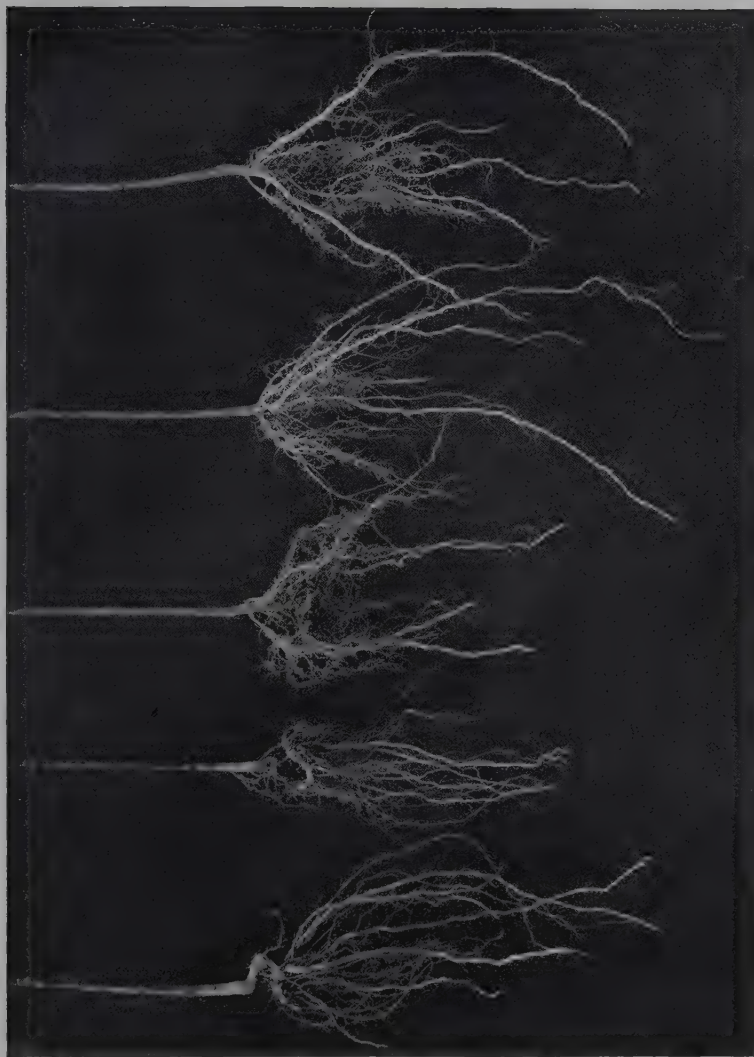


FIG. 5.

Illustrating variation in type of collar rooting on one year old seedlings. Left to right : no rooting at collar ; fibre only at collar, small roots and fibre at collar ; medium sized roots at collar ; large roots at collar.



FIG. 6.

Illustrating extent of rooting on the shoots from the stools. Left to right: well rooted stock; moderately well rooted stock; poorly rooted stock.

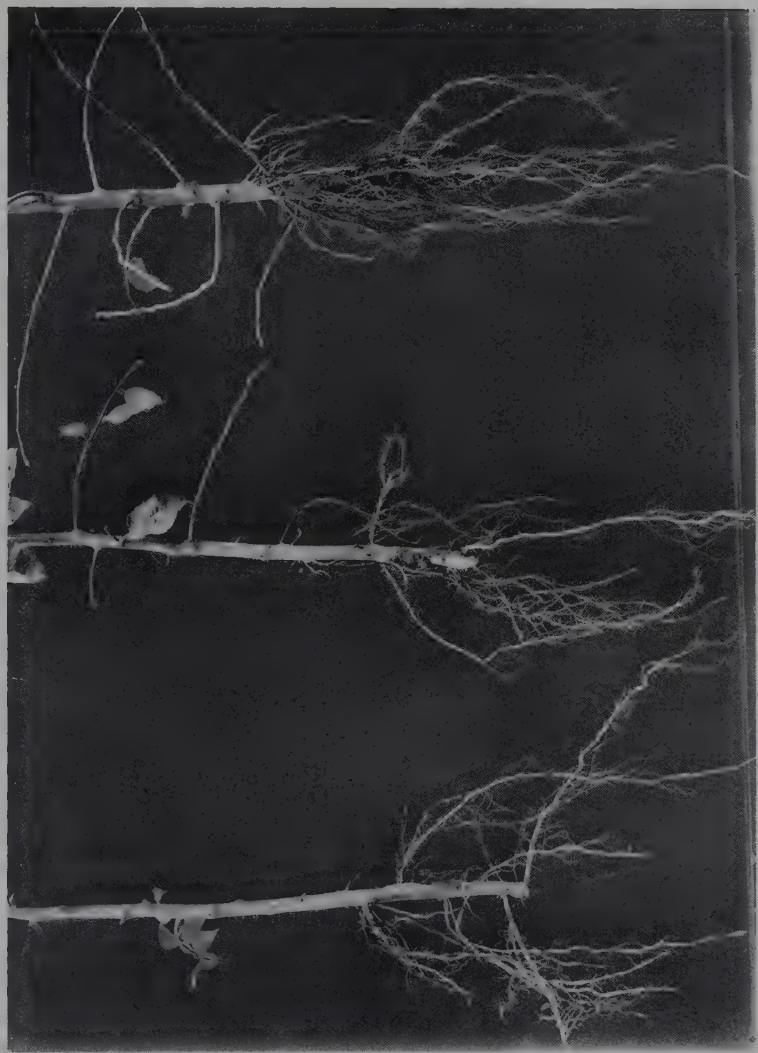


FIG. 7.

Illustrating variations in the type of rooting on shoots from the stools. (Left) coarsish roots, (centre) small roots, (right) fibre only.

MOSAIC DISEASE OF THE RASPBERRY IN GREAT BRITAIN

I. SYMPTOMS AND VARIETAL SUSCEPTIBILITY

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I. GENERAL INTRODUCTION.

AN investigation of raspberry mosaic-disease was undertaken at East Malling as a result of numerous enquiries from growers concerning the cause and significance of a yellow mottling of foliage in their plantations, and its possible relation to a stunting and progressive degeneration of the stools thus affected.

In 1921 a study of these symptoms was started* on the variety trial plots at the Research Station. These plots were laid down in order to compare the general performance and cropping of botanically true varieties, selected according to the system of identification devised by Grubb (12), from an extensive collection of named commercial varieties obtained from widely distributed sources.

It was soon found that these true varieties differed consistently (i) in the nature and intensity of the mosaic leaf-symptoms, (ii) in the relative proportion of stools showing these symptoms, and (iii) in the degree of stunting of affected stools.

In 1924 a preliminary field experiment was started, to find whether the observed symptoms persisted after transplanting, or were primarily the result of unfavourable local soil conditions. *Baumforth Seedling B* was the principal variety selected for this experiment, both on account of the distinctness of its leaf mottling, and the large proportion of canes with normal foliage. A selection was made from the entire collection of strains of this variety derived from widely separated localities (1) of stools showing the characteristic leaf-mottling, and (2) of stools free from such symptoms and as widely separated from affected stools as possible. These stools were divided, and forty mosaic and forty healthy canes were selected and planted out in order to observe their subsequent behaviour. To eliminate possible variation due to position the canes were planted in alternate sets of five healthy canes and five mosaic canes. During four consecutive seasons following planting each plant was examined minutely at frequent intervals, and notes made as to type and intensity of

* Mr. N. H. Grubb and Mr. A. M. Massee were solely responsible for this study in its initial stages. In 1923 the present writer started a general investigation of disease in relation to raspberry cultivation, and collaborated with Messrs. Grubb and Massee in subsequent work on raspberry mosaic-disease.

symptoms, vigour of growth of the stool, etc. It was found that every mosaic cane gave rise to a stool which persistently showed similar symptoms, and no cases of natural recovery were subsequently recorded. On the other hand no symptoms appeared during the first season on stools derived from the healthy canes. Subsequently a small proportion of these stools developed symptoms every season. In 1927, however, in spite of the close proximity of the healthy and mosaic stools on this plot, symptoms had still not appeared on 50 per cent. of the original healthy stools. It was observed that the stools with mosaic symptoms were for the most part less vigorous than the stools free from such symptoms, but the rapidity and degree of this loss of vigour varied considerably. It was concluded (1) that the mosaic leaf symptoms were caused primarily by a principle inherent in the plant itself, not by defective local conditions, (2) that this principle invariably persisted in the infected plant and its progeny, and (3) that its presence was associated with a steady loss of vigour.

In 1925 attempts were made to raise healthy stools from stools showing mosaic, by selecting and planting out from such stools "spawn canes" which themselves showed no leaf symptoms. Invariably, however, such canes gave rise to stools which developed mosaic symptoms in the season following transplanting, indicating that the infective mosaic principle was rapidly distributed throughout the entire plant-system after their initial infection.

The absence of any visible pathogen in canes showing mosaic symptoms, the persistence of these symptoms, the systemic distribution of the disease, and its broad resemblance to virus diseases of the raspberry described by American workers (see IIA), suggested that the symptoms in question were induced by a virus. This was confirmed by transmission experiments in 1926 and 1927, when it was found possible under controlled conditions to induce leaf-mottling (identical with that observed in the field) on healthy plants of the variety *Baumforth Seedling B* by grafting on to these plants portions of mosaic canes of the same variety. Numerous attempts to transmit the symptoms by the transference (by various mechanical means) of expressed juice from mosaic plants to healthy plants of the same variety yielded negative results.

Having established that the foliage mottling on the variety *Baumforth Seedling B* was a symptom of a virus disease, subsequent work (from 1928 onwards) has proceeded along the following lines :—

1. Detailed observations on symptoms and varietal susceptibility carried out on the variety plots at East Malling and on commercial plantations throughout the country and in the Scottish raspberry growing districts.
2. An analysis and correlation of the data obtained by field observations by means of grafting experiments.
3. Field experiments to determine methods of control.

4. The investigation of the insect-fauna of the raspberry in relation to possible insect vectors of the disease.

Up to the present time the work carried out by the Entomology Section under the last heading has yielded negative results. Although the natural *agent of spread* of the disease is at present unknown, considerable data have been collected by means of field experiments (under heading 3) as to the *mode of spread* of the disease in commercial plantations, on the basis of which a system of control was formulated. Experiments to test this system were commenced at the Research Station in 1927, and at the present time it is being successfully applied on fruit farms in Kent and Sussex (19).

II. LITERATURE.

A. AMERICAN.

Most of the literature on virus diseases of the raspberry deals with diseases occurring in North America, where descriptions of diseases subsequently shown to be virus diseases appeared as early as 1891. An excellent account of the early stages of the American investigations is given in an important paper by Bennett (1) in 1927. Previously to the publication of Bennett's paper three main diseases had been recognized, namely, *Mosaic*, *Curl* and *Streak** (26, 11, 21, 22). *Mosaic* was mainly distinguished from *curl* in that stools infected with the latter did not develop the leaf mottling characteristic of the former. *Streak* occurred exclusively on the black raspberry (*Rubus occidentalis*). In 1927 Rankin (23) stated that the only commercially important disease of red and purple varieties in New York was the "true infectious mosaic", and distinguished the latter from leaf-curl and a disease "of doubtful nature" referred to as "Mild mosaic". He pointed out the considerable differences between the effects of mosaic on the red and on the black raspberry. On the latter severe necrosis took place and stools were commonly killed outright; on the former no necrosis was observed, but infection was followed by a progressive dwarfing and loss of vigour, the eventual death being only indirectly due to the mosaic infection. In the same paper, in addition to extensive description of transmission and control experiments, varieties were classified according to their relative susceptibility and "klendusity" (or infectibility, see p. 248) under uniform conditions. Varieties of red raspberry were further divided into five groups according to the type of symptoms characteristic for the variety in an average season at Geneva (N.Y.). It was stated that these types of symptoms were "definitely correlated with the amount of dwarfing and degree of injury caused, and are therefore in reality merely expressions of variable susceptibility".

* Also known as *Eastern Blue Stem* (28) and *Rosette* (6).

In the same year Bennett (1) distinguished five distinct types of virus disease on the basis of symptom analysis, viz. *Curl*, and *Red Raspberry Mosaic* on red, black and purple varieties; *Mild Mosaic*, *Yellow Mosaic*, and *Streak* on black varieties only. The original "true infectious mosaic" of Rankin was therefore subdivided by Bennett into three symptom types of which one only, *Red Raspberry Mosaic*, was said to occur on red raspberries. In 1928 the same author (2) recorded the occurrence of yellow mosaic on both black and red raspberries and also on dewberries. In 1929 he stated in a brief note that "further experiments and results in the transmission of raspberry mosaic indicate that symptoms of mottling may be caused by a larger number of viruses than has hitherto been recognized". He regarded yellow mosaic as a definite type "distinguishable from the other mosaics by colour of foliage, time of incubation and rate of dispersion of the virus in the plant". Other mosaics differed chiefly in the severity of symptoms, and could not be sub-classified on the basis of symptoms alone, i.e. severe cases of mild mosaic graded imperceptibly into the less severe forms of red raspberry mosaic. He tentatively suggested the interaction of two or more viruses to account for such variation in symptom intensity, and provisionally classified these two mosaics under a single group. He also recorded instances of the separation of yellow mosaic virus from the red raspberry mosaic—mild mosaic virus complex in cases of combined infection by both diseases, in virtue of the more rapid movement of the latter.

In 1930 Rankin (24) in a brief note concluded that mild mosaic (on black raspberries) was an expression of red raspberry mosaic and not a distinct disease. In the following year the same author suggested that the mosaics of black raspberries were due to three viruses which he termed, Virus 1, Red (raspberry) mosaic; Virus 2, Yellow mosaic; and Virus 3, Mild mosaic. To Virus 1 he attributed both the red raspberry mosaic and mild mosaic symptoms of Bennett, only excepting the "small dot like type of symptom" of the latter, which he assigned to Virus 3, with the proviso that it was "doubtful whether this small residue represents a virus disease".

In 1932 Bennett (5), in commenting on the above classification in relation to red raspberry mosaic and mild mosaic, said, "Since there is a graduated range of severity of symptoms from very mild to very severe, and since so little is actually known regarding the properties of the causal agent, it seems questionable whether the present state of our knowledge justifies the use of virus or viruses as a basis for classification in this group of symptoms. It seems best for the present to consider all of the temperature limited, necrosis-producing forms of mosaic as belonging to one group, and perhaps caused by one virus, or by several strains of virus all of which have had a common origin." He visualized the possibility that red raspberry mosaic (which now included the former

mild mosaic) may be caused by a single virus in different stages of virulence, and concluded that under Michigan conditions there are "two general types of mosaic on raspberries, blackberries and dewberries" both of which occur on the red raspberry, viz. yellow mosaic and red raspberry mosaic. On black raspberries the latter produces considerable necrosis of tissue, while the former does not. On red raspberries necrosis does not occur with either type. On both black and red raspberries yellow mosaic has "a high temperature maximum for symptom expression", whereas red raspberry mosaic has a low temperature maximum, resulting in a considerable variation in the severity of symptoms on leaves produced at different times of the year.

A comparison of these two main types of mosaic (yellow mosaic and red raspberry mosaic) recognized at the present time by the American workers, with the two principal symptom types occurring on the red raspberry in this country and described below (viz. types *b* and *c*), will show that certain distinguishing characters are common to both sets of types, e.g., the masking of symptoms of red raspberry mosaic and of type *b* symptoms by high temperatures. It is clear that a final comparison to investigate possible identity can only be made by infecting under uniform conditions virus free canes of British varieties with the American mosaics and vice versa. Such transmissions could be readily carried out by the grafting methods used by the present writer for the analysis of symptoms occurring on the East Malling plots.

B. EUROPEAN.

In this country Grubb, Massee and the present writer (13, 16, 17, 18, 19) have issued reports from time to time written mainly for the information of the growers, and based on observations and experiments which will be described in detail in the present and forthcoming communications. Grubb (15) and Swarbrick (27) have also included notes on relative varietal susceptibility to mosaic in reports of cropping trials at East Malling and Long Ashton respectively.

In Germany in 1927 Müller (20) briefly described the symptoms of a mosaic disease of raspberries, and stated that leaf-curl had not been observed up to that time.

In Czecho-Slovakia, Blattný (9) in 1927 described the following three types of mosaic disease in addition to a leaf-curl disease, (a) *Ordinary mosaic* of two forms distinguished by the presence or absence of a blister-like deformation in addition to the mottling, (b) *Speckled mosaic*, a very mild form found on wild raspberries (the leaves mainly retain their normal green colour whilst a few scattered yellowish specks appear on the youngest), (c) *General mosaic*, causing a yellow discoloration of the whole leaf, advancing inwards from the margins, which are slightly curled downwards. The incidence of these symptoms was found to decrease with the increase of altitude of the plantation. In 1929 Baudys

(8) reported that the sharpness of distinction between the above four "virus diseases" varied with the altitude of the host plant, and that all combinations of symptoms commonly appeared on the same plant. He considered that this evidence conflicted with the view that several distinct types of raspberry mosaic existed.

A summary of American and European work on the transmission of mosaic by insects and artificial means has been deferred to a forthcoming communication dealing exclusively with this aspect of the investigation.

III. LEAF SYMPTOMS.

The only symptom by which mosaic disease can be identified and distinguished from other diseases of the raspberry is a yellowish mottling or speckling of some of the leaves of infected stools, due to a deficient development of chlorophyll in scattered areas of the laminae. The mottled or speckled leaves are commonly curled, twisted or distorted in varying degree, but this is by no means always the case. These symptoms are most clearly seen on the leaves of first-year canes or "new canes". On the fruiting canes a discoloration of the leaves normally takes place early in the season, and masks true mosaic mottling. Mosaic is not visible on the first leaves unfolded in the spring. It has been observed as early as the end of April, but in most seasons it is not commonly visible on the fruiting canes till the middle of May, and is not distinct on the new canes till early June. From this time the symptoms persist until they are masked by the normal autumnal discoloration. It does not follow, however, that all the leaves produced on an infected cane from early June onwards will be mottled. In the case of the variety *Baumforth Seedling B* for instance, a zonation, or intermittent development of symptoms, has frequently been observed, when the basal or earliest produced leaves are normal and are followed by a zone of mottled leaves, and these again by a zone of normal leaves, and so on. Almost invariably in such cases the last leaves to unfold at the close of the season are mottled. Other canes in the same plantation may not exhibit the zonation, and in such cases the apical leaves are invariably mottled from the earliest appearance of symptoms onwards.

From the earliest stages of the investigation it has been noted that variant forms of leaf-symptoms occur on different varieties. This variation is doubtless in part the result of varietal differences in the morphology of the host plant. Later, however, different types of symptoms were found on neighbouring stools of a single variety (*Baumforth Seedling B* in the first instance).

Further detailed surveys of symptoms on the wide range of varieties at the Research Station in the light of this fact made it possible, after allowing for

differences due to variety alone, to group the symptoms into three main types. These types arranged in ascending order of the degree of leaf-deformation produced, will be referred to as symptom-types *a*, *b*, and *c*. They are to be regarded simply as a convenient mode of describing the range of mosaic leaf-symptoms observed. Their inter-relation will be discussed in a subsequent communication describing experiments on the analysis of symptoms by the method of transmission by grafting.

1. *Type "a" symptoms on Mitchell's Seedling (Plate I, Fig. 1).*

On leaves showing type *a* symptoms chlorotic mottlings of varying size and irregular shape are evenly distributed over the entire leaf (contrast with type *b*) the individual chlorotic patches are not appreciably sunken, and the leaf is not curled or distorted but is quite normal in appearance except for the mottling (contrast with types *b* and *c*). This type also occurs on *Bath's Perfection* and other varieties. A similar evenly distributed mottling, unaccompanied by curling or distortion, has commonly been observed on the lower leaves of the new canes of stools known to be free from mosaic disease, and is probably brought about by shading or other purely local factors. Such mottling can be distinguished from type *a* mosaic by its appearance on the lower or older leaves only, whereas if type *a* symptoms occur on the lower leaves they can also be detected on the younger leaves.

2. *Type "b" symptoms on Baumforth's Seedling B (Plate II).*

Mosaic leaf-symptoms were first studied in detail on the variety *Baumforth's Seedling B*, and the symptoms most commonly observed on this variety were eventually referred to as type *b* symptoms. The chlorotic areas or mottling vary in colour from pale green to greenish-yellow, and in size from minute specks to patches about 2 mm. across, not clearly delimited from the dark green areas. They are only slightly sunken, transverse sections made through these areas indicating that there is a gradual and very slight decrease in thickness of the lamina in passing from the green to the chlorotic areas, due to a slight decrease in the depth of the palisade layer of cells. The dark green areas between the chlorotic areas are slightly convex as seen from above. The chlorotic areas are never evenly distributed over individual leaflets, but are generally concentrated between the main veins, giving the leaf a slightly striped appearance, and often they are more crowded towards the margins. This mottling is accompanied by a symmetrical downward curling of the leaflets about the midribs, and sometimes by a downward curling of the midrib itself. One of the most striking features of this type of symptom is the varied degree of mottling and curling of each of the leaflets composing a single leaf. Commonly one side of a complete leaf is affected more seriously than the other side; for example on a leaf consisting of

a terminal leaflet and four lateral leaflets, the two lateral leaflets and half the terminal leaflet on one side of the main leaf trace are more severely mottled and curled than those on the other side (see Plate II). A further distinguishing feature is that all the symptoms described are masked or entirely suppressed on leaves produced under hot summer weather conditions. The result is the zonal manifestation of symptoms so commonly observed and already described, the symptoms appearing most distinctly on leaves produced in the early and latter parts of the season and being masked in varying degree on the mid-season leaves.

3. Type "c" symptoms on *Baumforth's Seedling B* (Plate III).

This type of symptom was first distinguished in 1926 on the field observation plot of the variety *Baumforth's Seedling B* already described (see p. 237). The majority of the diseased stools on this plot exhibited the ordinary type *b* symptoms, but on certain stools all the leaves showed a form of speckling (rather than mottling) diffusely and evenly distributed over the majority of the leaves of all the canes. Subsequent records and observations on this plot and elsewhere confirmed the persistent and distinct character of these symptoms, which were thereafter referred to as type *c* symptoms. This type as it occurs on *Baumforth's Seedling B* is distinguished from type *b* symptoms (on the same variety) in the following particulars. The individual chlorotic spots are bright yellow to greenish-yellow and are more sharply defined and easily distinguished than those of type *b*. Each spot is irregular in shape and sharply angular and about 2 mm. across—in advanced cases somewhat more. Unlike type *b* spots, they are deeply sunken or embossed. Transverse sections made through a spot show that there is a very sharply marked decrease in the thickness of the palisade layers and a consequent decrease in thickness of the leaf in the region of the spot, the palisade cells being in extreme cases indistinguishable in shape from the mesophyll parenchyma. On holding an infected leaf in front of a light the spots are seen to be much more translucent than the green parts of the leaf, and their sharp angular outline stands out clearly. The spots are generally evenly distributed over the leaf surface (i.e. there is no aggregation in any particular region) and individual spots commonly cut across a leaf vein or midrib. Spotting of this type is invariably accompanied by a curling of the laminae, but in this case the curling ultimately takes the form of an irregular or asymmetrical twisting, crumpling or distortion of the whole leaf. In its incipient stages this distortion is very slight, but in advanced cases becomes very pronounced (see Plate III). Finally, unlike type *b*, type *c* symptoms are not masked under hot summer weather conditions. From the time that the apical leaves show the symptoms clearly (about June) every leaf which subsequently unfolds shows similar

symptoms. Owing to their small size the apical leaves at any time in the season appear to be more severely spotted and distorted than the mature leaves lower down the cane.

4. "*Leaf-curl*" on *Helston*.

It has been noted that in symptom types *b* and *c* the appearance of chlorotic spots on the leaves is accompanied by a varying degree of leaf curling and distortion. In 1923 the leaves of certain stools of the variety *Helston* were observed to be abnormally curled, but without any trace of mottling. The following winter selected stools showing these symptoms were divided and planted on the observation plot already mentioned, together with canes derived from apparently normal stools. In subsequent seasons the leaf-curl symptoms were found to persist in the progeny of the original leaf-curl plants. Stools derived from normal plants, on the other hand, remained normal. This is the only case so far recorded at East Malling of a disease whose symptoms resemble the leaf-curl disease described by American workers (1, 21, etc.).

5. "*Devon Chlorosis*."

A form of chlorosis has been observed on leaves of the *Devon* variety, which is often confused with the symptoms of mosaic. This chlorosis is quite distinct from lime-induced chlorosis, and hitherto has been observed only on this variety. It occurs in varying intensity on a varying proportion of stools in every plantation of this variety examined, and provides a useful clue to identification.

There is no evidence at present of any relation between this chlorosis and mosaic. The two sets of symptoms which commonly, though not invariably, occur on the same stool can readily be distinguished by the fact that with "*Devon chlorosis*" the chlorotic areas are pale (whitish) yellow whereas those of mosaic are pale green to greenish-yellow. Consequently leaves with the former symptoms are much more vivid and distinct than mosaic leaves. In some plantations a large proportion of the leaf area is chlorotic, and the vigour of the stools is clearly below the normal. In other plantations a few leaves on stools here and there appear to have been lightly dusted with a pale yellow powder. The cause of "*Devon chlorosis*" is at present unknown.

6. *The Classification of Leaf-symptoms of other Varieties.*

Symptom types *a*, *b* and *c* as described above cover the range of leaf-symptoms recorded during the detailed survey of varieties carried out from 1922 to the present time, and provide a convenient method of describing the symptoms shown by any one variety. It should be noted, however, that although the symptoms in the main conform to these three types, the symptoms shown by

any one variety differ in certain details from those shown by other varieties. This is clearly due to varietal differences in the morphology of the host.

In the case of varieties with outstanding morphological features such varietal divergencies in leaf-symptoms are very marked. For example the leaves of the varieties *Pyne's Royal* and *Superlative* are naturally curled and crinkled. This is accentuated when the stool becomes infected with mosaic, and as a result it is extremely difficult, on the basis of observation alone, to classify the symptoms according to the three types.

More than one type of symptoms may occur on the same variety. Types *b* and *c* symptoms are described above on the single variety *Baumforth's Seedling B*. The same two types also occur on *Reader's Perfection*. In both these varieties it is common to find the two types combined on the leaves of a single stool.

Contrast in this respect the variety *Mitchell's Seedling*. In the Scottish raspberry district whence it originated and where it is still widely grown, type *a* symptoms appear exclusively. At East Malling type *a*, and in addition a more severe type (resembling type *c*) develop, but in this case both types have never been observed on the same stool.

In the important variety *Lloyd George* it appears likely, from observations, that more than one type of symptoms is present, but their distinction is not so easy as on the other varieties mentioned. The ultimate classification of the symptoms on this variety, on such varieties as *Pyne's Royal* and *Superlative*, and on other varieties whose symptoms fall more readily into one or the other symptom-type, cannot be made on the basis of observation alone, but must ultimately depend on some method of analysis such as grafting. The application of this method to such an end was started in 1928, and has provided some evidence indicating that the variant types of leaf symptoms described above can be related to two distinct forms of mosaic disease. The further discussion of these symptom types will therefore be held over pending the description of these grafting experiments.

7. *The Reading of Symptoms in the Field.*

Before the elimination of mosaic-infected stools from field plantations of any variety can be accurately carried out, a careful study must be made of the symptoms shown by that variety at all times in the season and under varying seasonal and weather conditions. In incipient stages mosaic symptoms only appear on relatively few leaves, and the mottling on such leaves is commonly very faint and easily overlooked. It is only by constant contact with diseased plants of a particular variety for a number of seasons that such symptoms can be detected and distinguished from mottling due to local and transitory causes (see p. 243), i.e. that "border line cases" can be adjudicated with confidence.

In addition to the masking of type *b* symptoms by high temperature referred to above (p. 244) all types of symptoms are temporarily masked to a considerable degree (a) when the leaves are wet with rain or dew and (b) when they are viewed in direct sunlight. Critical inspections, which must be carried out early in July or as late as possible (i.e. shortly before autumnal discoloration commences) in order to avoid the temperature-masking factor, must therefore also be made when all the leaves are dry and (if possible) in diffused light (dull weather). If they are carried out in sunny weather the stools under observation must be shaded by the observer placing himself so that his shadow is cast on the stool he is inspecting. Mosaic leaves can be identified with greater ease by wearing yellow tinted spectacles.

IV. THE EFFECT OF MOSAIC DISEASE ON STOOL DEVELOPMENT.

Stools of most raspberry varieties commence to deteriorate at varying rates from the first appearance of the leaf symptoms. In passing along a row in a plantation of a susceptible variety the mosaic stools, which are usually grouped together, stand out in contrast with their neighbours by (1) their mottled foliage, (2) their deficient cane production and (3) a general dwarfness and stunting of the canes and fruiting laterals produced. In no case, however, has a necrosis of a stool or any part of a stool been observed, which could be ascribed directly to the action of the virus (contrast with virus diseases of black raspberries in America (1, 25)). Infected stools of susceptible varieties eventually die, but the actual death usually takes place some considerable time after the stool has become worthless, and is generally caused by other agencies, encouraged by the loss of condition due to the virus. Further there is every indication that the undoubted loss of cropping power of infected stools is due entirely to this loss of general vigour and not (as in the case of black-currant "Reversion") to any flower sterility directly caused by the disease.

I. RELATIVE VARIETAL SUSCEPTIBILITY AND INFECTIBILITY AT EAST MALLING.

Early in the survey for mosaic of varieties on the trial plots it was observed that the varieties differed not only in their leaf symptoms, but in the proportion of stools showing those symptoms, and in the degree of degeneration associated with their appearance. These differences were clearly due in part to the fact that the plots were not planted originally with mosaic-free material raised under uniform conditions. Thus different degrees of mosaic attack were recorded on plantations of the same variety planted with cane previously grown in different localities. Subsequent observations carried out over a period of some ten consecutive years have indicated beyond doubt that under uniform conditions of

growth varieties differ consistently both with regard to (1) their *apparent-infectibility*, i.e. the observed relative rate of increase in the number of stools showing mosaic symptoms, and (2) their *apparent-susceptibility*, i.e. the relative rate of degeneration of stools from the first appearance of mosaic symptoms on those stools.*

TABLE.

Relative Apparent-Susceptibility and Infectibility at East Malling.

I—Apparent-Susceptibility.	II—Apparent-infectibility.		
	A " Low ".	B " Moderate ".	X Undetermined.
A " Low "	Red Antwerp B Baumforth A MacLaren's Prolific	North Ward Hornet D Red Antwerp C Baumforth B Reader's Perfection Semper Fidelis A	Red Cross Burnet Holm Seedling Hornet E
B " Moderate "	Helston Goliath	Lloyd George Devon	Hornet A Norwich Wonder A
C " High "		Red Magnum Bonum ?Preussen	Superlative Norwich Market Mitchell's Seedling Scotch Victoria

In the Table certain commonly grown varieties are tentatively graded according to their relative apparent susceptibility and infectibility. The following is the system of classification adopted :—

- I. *Apparent Susceptibility*. The relative rate of degeneration of mosaic stools (i.e. stools showing leaf-symptoms).

Group A. " Low."

The vigour of growth and cropping of mosaic stools is not appreciably or only slightly less than that observed ten years ago.

Group B. " Moderate."

The average vigour of mosaic stools at the present time is definitely below that observed ten years ago, but the majority of such stools still bear crops.

* Two distinct characters are commonly included under the general term *Susceptibility*, i.e. (1) susceptibility to initial infection and (2) susceptibility to injury after infection. In this paper the former, determining the rate of spread of initial infection, will be termed *Infectibility* (Rankin (23) uses the term *Klendusity* in the same connection); and *Susceptibility* will be used (as by Rankin) in the latter sense, referring to the character determining the *rate of degeneration* of stools *after infection*.

Group C. "High."

The majority of mosaic stools at the present time are commercially useless.

- II. *Apparent Infectibility.* Relative rate of increase in the proportion of mosaic stools observed.

Group A. "Low."

The proportion of mosaic stools has not appreciably or has only slightly increased during the ten year period.

Group B. "Moderate."

The proportion of mosaic stools at the present time is relatively high compared with the observed proportion ten years ago.

Group X. "Unknown."

Every stool has shown mosaic symptoms from the time of the first survey.

It must be emphasized that the above classification of varieties is based solely on surveys (covering a ten year period) carried out on trial plots planted at various times from 1919 to 1926, and subsequently run for periods of approximately five years. It must therefore be regarded as subject to ultimate verification by means of long-period field trials planted with virus-free canes of each variety, raised under uniform conditions.

This classification is also subject to revision on the results of controlled susceptibility tests and symptom analyses by methods of artificial transmission. Grafting experiments commenced in 1928 (a detailed account of which is being prepared for publication) have indicated that the leaf-symptoms of certain varieties may remain suppressed for considerable periods after infection. It is therefore necessary to determine by such methods the capacity of each variety to carry the disease without manifesting leaf-symptoms. There is evidence from field experiments that certain varieties, such as *Bath's Perfection* and *Pyne's Royal*, possess this character to an outstanding degree, i.e. that a large proportion of the stools of these varieties, upon which mosaic symptoms cannot be detected, are actually infected. The apparent susceptibility and infectibility of such varieties, therefore, probably bears but little relation to their actual susceptibility and infectibility, and such varieties are consequently omitted from the Table pending the carrying out of grafting tests.

These grafting experiments have also shown that the occurrence of the distinct types of leaf symptoms described above is an indication of the infection of varieties by more than one distinct form of mosaic disease. Experiments are in progress to determine the relative degree of injury caused by these forms of mosaic, and preliminary analyses of symptoms of certain varieties have been made in order to identify the form or forms of mosaic disease present, and, if more than

one form is present, to determine the relative susceptibility and infectibility of the variety to each form. Such an analysis is likely to provide an explanation of the apparent susceptibility of certain varieties in the field. Thus some varieties (e.g. *Red Cross*) may appear to have a low susceptibility because they are highly infectible by an innocuous form of mosaic and rarely, if at all, infected by a more virulent form.

If the grower bears in mind that the Table is subject to revision and elaboration along the lines described above, this tentative classification will provide him with a guide in his selection of varieties and canes for planting up. Two main principles should be borne in mind :—

- (i) The higher the *susceptibility* of a variety the greater is the immediate importance of planting up with mosaic-free canes.
- (ii) Having made allowances for differences in the age of varieties, it follows that the higher the *infectibility* of a variety the greater will be the difficulty in obtaining mosaic-free canes from the usual commercial sources of supply (i.e. surplus canes dug from fruiting plantations).

Thus it is more important to plant with virus-free cane of *Lloyd George* than of *Baumforth's Seedling A*, and it is more difficult to obtain such cane in the case of *Lloyd George*, since its infectibility is high.

It is one thing, however, to consider the control of raspberry-mosaic disease in relation to the *immediate success* of projected plantations, and quite another to consider it in relation to the future career and commercial survival of the varieties to be grown. When this latter wider standpoint is adopted by the grower it will readily be seen that even in the case of varieties with low infectibility (e.g. *Baumforth Seedling A*), unless some system is adopted for eliminating infected stools from the commercial sources of cane supply (at the present time the commercial fruiting plantations), all the available cane of such a variety will eventually become infected. When such a condition is reached (as it has been reached by the varieties in the Infectibility Group X) it will only be a question of time (depending on its susceptibility) before that variety becomes useless. Its ultimate survival can only be assured if it is completely resistant to the disease. The nearest approach to such a condition hitherto observed is the variety *Red Cross*. This variety has been under constant observation at East Malling and on commercial plantations in all parts of the country since 1922, and during this period no single stool has been found which could be pronounced free from mosaic infection. In spite of this apparently total infection of the variety, however, it has consistently taken its place among the heaviest cropping varieties in the Research Station trials (14, 15) and elsewhere, and no appreciable deterioration of its vigour has taken place. Hitherto *Red Cross* has proved unique in this respect. In the case of all other varieties in the low-susceptibility

(A) group, there has been evidence of a slight deterioration of mosaic stools over long periods. Specific instances of such slow degeneration will be considered in connection with the relation of locality to susceptibility (see below); meanwhile it can be concluded that under the present system of cane distribution even varieties with the lowest susceptibility and infectibility must eventually become completely degenerate and commercially useless.

On the basis of field experiments carried out at the Research Station and on growers' farms since 1926 a system of control has been formulated, and is already in active use, whereby the grower can provide himself with reliable mosaic-free canes of certain important varieties. A preliminary account of this system has already been published (19).

2. THE INFLUENCE OF LOCALITY ON THE APPARENT SUSCEPTIBILITY AND INFECTIBILITY OF VARIETIES.

The classification of varieties in the Table is only applicable in a strict sense at East Malling. Although a final comparison of the susceptibility and infectibility of varieties in differing localities can only be made by simultaneously planting observation plots in each locality with uniform mosaic-free canes, extensive surveys of commercial plantations in widespread localities have indicated that in Kent and the neighbouring counties the same classification can be applied with occasional exceptions, probably due to the complicating reaction of differing soil and cultivation. In certain more distant areas the susceptibility and infectibility of varieties are not, generally speaking, the same as at East Malling. As a rule, however, the relative position of varieties in the susceptibility and infectibility scale has been found to be similar in most localities in this country. The Table can therefore be applied outside Kent *in a relative sense* although the definition of the groups may have to be modified for distant localities. In the West of England, for instance, although the susceptibility of varieties is on the whole lower than that at East Malling (i.e. varieties take longer to succumb to the disease), the *relative* susceptibility of the varieties appears to be very similar (27).

Visits to the Scottish raspberry growing areas have provided evidence that the apparent susceptibility and infectibility of certain of the most popular varieties in these areas are strikingly less than at East Malling. The outstanding instance of this is *Mitchell's Seedling*. When the writer visited Scotland in 1924 and 1926 this variety (which was originally raised in Scotland) was one of the leading varieties in cultivation on account of its uniform vigour and high cropping in spite of the fact that every stool examined showed type *a* mosaic-symptoms, the only type hitherto observed on this variety in Scotland.

At this time cane of this variety was collected from some of the best plantations in Scotland, and was planted out on the East Malling plots. For the first

year or so it produced small crops and then started to degenerate. At no time has its growth and performance approached that of Scottish plantations, and subsequent plantings have rapidly degenerated until the small stock of cane remaining is, at the present time, completely worthless. This rapid failure of the variety at East Malling has been associated with a development of mosaic symptoms on all the stools.

On many of the stools type *a* symptoms similar to, but slightly more distinct than, those observed in Scotland appeared (see Plate I, Fig. 1). A large proportion of the stools, however, developed a more advanced type of symptoms conforming to type *c* (Plate I, Fig. 2) but types *a* and *c* symptoms have not been observed to occur on the same stool. In 1932 the present writer re-visited the Blairgowrie district, when it was found that *Mitchell's Seedling* is rapidly dropping out of cultivation and is being replaced mainly by *Lloyd George*, the reason repeatedly given being that the vigour of the former variety has decreased markedly of late years. This was confirmed by an examination of existing plantations, when it was found that the general vigour of growth of the variety was markedly below that observed in previous years. Again type *a* symptoms were detected on all stools. It can be concluded from these observations (a) that the apparent *susceptibility* of *Mitchell's Seedling* to mosaic is much greater at East Malling than in Scotland and (b) that in Scotland in spite of its low susceptibility, a slow degeneration of the variety has taken place following an initial infection of all the available cane. The relation and significance of the two types of symptoms exhibited under East Malling conditions will be discussed in a future communication describing analyses carried out in 1928 by grafting methods. Meanwhile the above facts provide a striking indication that even in the case of varieties with low susceptibility it is necessary to take precautions to propagate mosaic-free cane if their ultimate survival is to be secured.

In 1932 there was also evidence that under Scottish conditions the *Lloyd George* variety exhibited a much lower apparent-susceptibility and infectibility than at East Malling. Certain experimental data and observations have indicated, however, that symptoms on this variety may be inhibited to a considerable extent under Scottish conditions, and trials of Scottish cane have been recently planted at East Malling to test this point.

ACKNOWLEDGMENTS.

The writer wishes to tender his grateful thanks to Mr. Norman Grubb, to whom he is especially indebted for his continued collaboration and valuable criticism in every detail of the investigation, to Mr. A. M. Massee for considerable assistance in the early observation work and to Dr. H. Wormald for much help in the preparation of this paper.

SUMMARY.

1. A general introductory outline is given of the investigation of raspberry mosaic disease started at East Malling in 1921, and the conclusions reached up to the present time are discussed in relation to recent work on raspberry virus diseases in America and Europe.

2. The range of leaf symptoms observed on an extensive collection of varieties at East Malling is classified under three main symptom types as follows :

Type a. Mottling distributed evenly over the entire leaf surface, chlorotic patches not appreciably sunken and not accompanied by any curling or distortion of the laminae.

Type b. Chlorotic patches ill defined, tending to group themselves towards the leaf margins and between the main veins, slightly sunken and accompanied by a symmetrical down-curling of the laminae. about the midrib. The degree of mottling and of down-curling both vary on the individual leaflets of a single leaf. This type of mosaic is masked by high summer temperature conditions.

Type c. Chlorotic spots sharply defined, deeply sunken or embossed, randomly scattered over the leaf surface and accompanied by an asymmetrical twisting or crumpling of the laminae. This type of mosaic is not masked by high summer temperatures.

3. The above symptoms are distinguished from *leaf-curl* (only observed on the variety *Helston*) and a form of chlorosis peculiar to the variety *Devon*.

4. Mosaic symptoms are temporarily masked if the leaves are wet or are observed in direct sunlight.

5. A tentative classification of varieties according to their relative apparent susceptibility and infectibility is submitted, based solely on field observations (over a ten year period) on the East Malling trial plots.

6. The application of the above classification in other localities is discussed, and specific instances of the influence of locality on the apparent susceptibility and infectibility of varieties are given.

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PLATE I.



FIG. 1.



FIG. 2.

Leaves from new canes of *Mitchell's Seedling* showing type *a* (Fig. 1) and type *c* (Fig. 2) mosaic symptoms (Natural size).

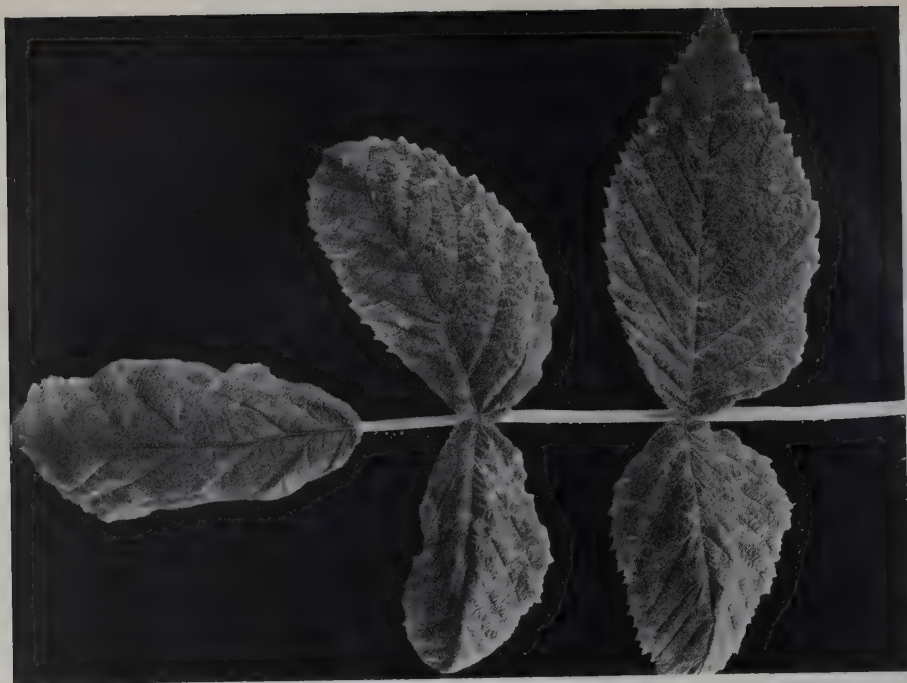


FIG. 2.
Leaves from new canes of *Baumforth's Seedling B*, showing type *b* mosaic symptoms.

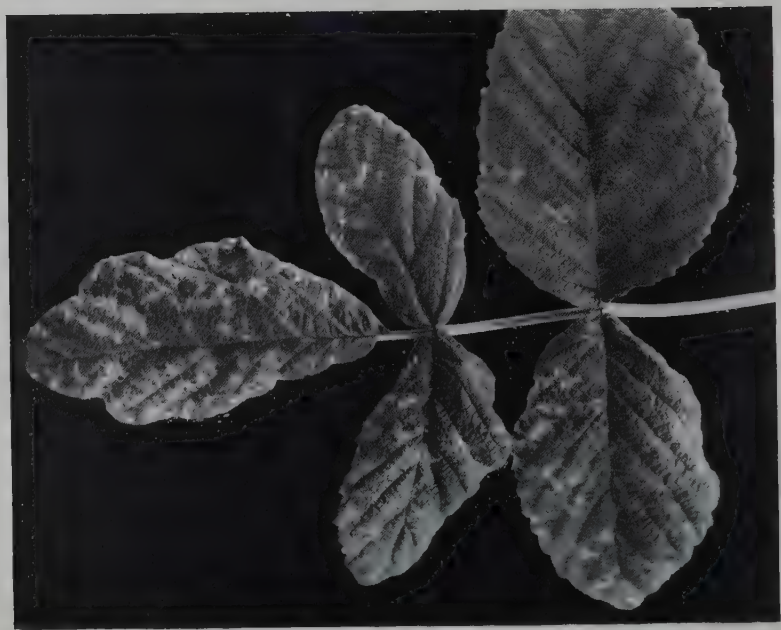


FIG. 1.



FIG. 1.



FIG. 2.

Leaves from new canes of *Baumforth's Seedling B* showing type *c* mosaic symptoms, Fig. 1 incipient, Fig. 2 advanced (Natural size).

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BOOK REVIEWS

THE APPLE. By SIR A. DANIEL HALL, K.C.B., LL.D., Sc.D., F.R.S., and
M. B. CRANE. (London: Martin Hopkinson, Ltd. 1933.)

The publication of this work, the appearance of which has been awaited with keen interest, places apple growers in this country in the happy position of having available in comparatively small compass the story of that fruit and its culture written particularly from their own standpoint and in the light of the most modern knowledge of the subject. The names of its authors carry their own guarantee as to the trustworthiness of its contents and the list in the Preface of those to whom acknowledgment of assistance is made ensures that the points of view of the practical grower have been thoroughly considered and that in practical as well as scientific detail the book speaks authoritatively.

It is for the practical man that the work is primarily written. To him in particular Sir Daniel Hall in his Preface addresses a challenge to command the home market, leaving him in no doubt as to the strength of the position at his disposal. But it is not the grower with commercial interests who is solely in view: the breeders of new varieties, the nurseryman, and all who grow apple trees in their private gardens will find information which they cannot afford to disregard and which for the first time has been made easily accessible and brought within the covers of a single book.

It is not, however, a handbook of apple culture in the ordinary sense. It is true that those who are looking for such a work will find here the most recent developments of knowledge and experience on the practical side described in such detail as space has permitted. But incorporated also in an appropriate form are the results of scientific research in each phase of the subject touched upon and it is the treatment of the subject in these respects which gives the book a unique character among the literature on apples and makes it of high service to all interested in that fruit, whether as growers, teachers or investigators in any branch pertaining thereto.

For it is unquestionably a work deserving of attention by scientific workers. So rapidly is research advancing that it is becoming increasingly difficult for the physiologist, the plant pathologist, the chemist or the geneticist specializing on pomological problems to keep in touch with all the developments affecting the culture and marketing of the fruit brought about by the labours of his co-workers in the kindred sciences. Here the stage which has been reached by science and its application to practice can be found presented in concise form and the adequate references to the literature of the subject given will meet the needs of those requiring more detailed information.

The comprehensive character of the book will be sufficiently indicated by the following brief survey of its contents. After an interesting chapter on the history of the apple it reviews the character of the apple itself, including the range of structural, nuclear and chemical variations. It then deals with the highly suggestive and important contributions to knowledge made by genetical research and their bearing on the problems of the apple breeder in particular. Soil, manuring and cultivation in their related aspects are next described and the particular case of the grass orchard, is also given attention. The make-up of the individual tree, with the associated stock and propagation problems, is next dealt with and that section is followed by a very practical chapter on "lay-out" as influenced by recent additions to knowledge on rootstocks and

related subjects. The building up of a fertile tree is then discussed, after which in succession the important diseases and pests and their control, the choice of varieties, and the harvesting and storage of the crop receive notice. In addition to an adequate bibliography an appropriate glossary is appended.

It will be understood that in a book of this type, dealing with systems of practice still in a fluid state and constantly affected by current research, individual readers will not see eye to eye with the authors on every point. As a whole, however, it may be claimed that if growers proceed in accordance with the outlines of practice indicated they will approximate to the best results possible in the present state of knowledge. Perhaps the lists of varieties recommended for culture will, as usual in such cases, be most open to criticism. Regarded generally, it is difficult to see how the lists of selected commercial varieties can be materially improved. For garden varieties, however, American Mother and Lord Hindlip would seem to many to have greater claim to inclusion as dessert sorts than some of those chosen.

The illustrations as a whole are very clear and the only typographical error noted has been in the description of Fig. 21, facing p. 158, where Pearmain is spelt "Permain".

In conclusion, this book can be warmly recommended to all desiring information on the apple. It is lucid and easily readable, as one could expect any work by its authors to be, and the scientific aspects have been introduced in a manner which should certainly interest and not deter the lay reader. It fills a gap in existing literature for both the practical grower and the pomological research worker and adviser, and it is to be hoped that the authors will place English pomology still further in their debt by dealing similarly with our other hardy fruits in turn.

B. T. P. BARKER, Director, University of Bristol Agricultural and Horticultural Research Station, Long Ashton, Bristol.

September 28th, 1933.

PROBLEMS OF FRUIT TREE NUTRITION: POSSIBLE LINES OF APPROACH.

By T. WALLACE. (Imperial Bureau of Fruit Production Technical Communication No. 4, March, 1933. Price 2s.)

The importance of the two papers by Dr. T. Wallace, reprinted as *Technical Communication No. 4* by the Imperial Bureau of Fruit Production, lies in the fact that the emphasis is placed upon principles underlying manurial procedure. The writer makes it clear that no empirical rules can be given to the grower, who has to consider the problem of manuring in relation to the general problems of climatic conditions, soil, varieties under cultivation, and cultural practices available to him. These papers deserve the widest circulation because they give the reader, both practical and scientific, some guiding principles upon which to attack his special problem whilst leaving him under no delusion as to the fact that every fruit plantation presents its own problems, needing study and experiment before the successful solution is to be found for that particular case.

Dr. Wallace has attempted to ease the task of diagnosis for the practical man by culture experiments in sand and in solution in which the plants are supplied with a complete mineral nutrient solution from which in different cases a different element is omitted. Such deficiency experiments, coupled with

careful observation of the fruit trees over an extended period, have led to the recognition of most valuable diagnostic features, pointing to the lack of particular mineral nutrients, which may be applied in the field. Thus, for instance, a definite step forward has been possible in coupling leaf scorch under English conditions with potassium deficiency. Of course such diagnostic symptoms must always be used with caution, as is well illustrated by the difficult case of lime-induced chlorosis, but along these lines Wallace has very definitely advanced our knowledge of the relation of potassium to the water table of the plant and of the relative significance of nitrogen manuring to the grass orchards of the western counties and to the arable fruit areas of the eastern counties.

The different behaviour of Bramley Seedling and Allington Pippin under potassium deficiency conditions is a forcible reminder of the significance of the variety in relation to manurial treatment as to every other cultural problem. Evidence has been obtained that rootstock is also important in this connection, but here, as also with the time of application of the manure, practice must probably be determined for some years to come in the absence of essential information upon the scientific problems involved.

Nowadays two extreme standpoints are equally out of favour—we neither think that the root system of the plant behaves as a physical system which passively absorbs every salt present in the soil until its concentration within the plant is equal to that outside, nor that the plant is a biological entity which, by reason of some mysterious vital principle, absorbs only what it requires and rejects all toxic and useless solutes. We are prepared to build up our knowledge of the entry of mineral substances step by step upon experimental data. The experiments of Hoagland in California and of Steward at Leeds have shown that substances are often piled up in solution in the cell, against the concentration gradient, work is thus done and the necessary energy obtained from the metabolic activity of the cell. In the cells thus engaged in storing salts, this property seems to be associated with their active growth, and from this standpoint we may well ask where the controlling impetus lies to the accumulation of salts within the plant. In the spring the first signs of activity in the living tree often seem to be shown by the bursting bud. To what extent do such activities transfer salts from stem and rootstock to the growing shoot? Similarly, to what extent does root absorption depend upon the renewed growth of the root system in spring: is it different when thicker roots are being formed in late summer and how is the balance of salt supply between stock and scion influenced by their relative vigour of growth? Such questions arise upon every hand, but they can be much more precisely indicated and much more profitably taken up in the light of the pioneer work upon the mineral nutrition of the woody plant, carried out largely at Long Ashton and ably summarized in these papers.

A Foreword by Mr. R. G. Hatton refers also to two cognate communications issued by the Bureau. One of these, issued in stencilled form as *Occasional Paper 1*, gives details of Dr. Wallace's technique in pot culture experiments, and thus makes the results of his long experience with these methods readily available to the workers at other experimental stations. *Occasional Paper 2* consists of a translation of the author's summary of a Russian paper upon experimental data on orchard and small fruit manuring by S. T. Antoshin. As the full translation of this paper is available at the Bureau, the synopsis of its contents may enable the reader to learn if he wishes to consult it, but the brief summary with the critical editorial comments added suggest that the time is not yet ripe for a comprehensive discussion of manurial methods applicable to woody perennials.

J.H.P.

DAMPING-OFF AND OTHER ALLIED DISEASES OF LETTUCE

By M. M. ABDEL-SALAM, B.Sc., Ph. D.

A. INTRODUCTION.

Severe damping-off of lettuce was observed by the writer in the Slough district during the Winter months of 1929-30, the affected plants ranging from young seedlings grown in frames to older plants bedded out in unheated green-houses. Only occasional plants were affected in the latter case, but considerable damage, amounting to some 25 to 50 per cent. of the total stand, was seen in the frames. Illustrations of the latter are shown in Plate I, Figs. 1 and 2. The particular grower in question used the term "damping-off" for the disease affecting the younger seedlings and the term "drop" for that of the larger plants. The term "drop", it may be noted, is somewhat unfortunate, as it is liable to lead to confusion with the disease known by that name in America and caused by *Sclerotinia* species.

B. HISTORICAL.

The phrase "damping-off" has, since de Bary's days, been generally associated with the fungus *Pythium de Baryanum*. In 1892, however, Atkinson (1) isolated a sterile sclerotial fungus from cotton seedlings suffering from "sore-shin", a disease which is definitely of the damping-off type. He isolated the same fungus from damped-off seedlings of lettuce, beet, radish and several other plants in the hot-house, and proved by infection experiments the pathogenicity of the fungus, though he failed to identify it.

Stone and Smith (18) in 1900 described a moist brown-rot of the lower leaves of lettuce caused by *Rhizoctonia Solani*. They stated that the disease was not uncommon, though in general not of any great economic importance.

In 1901 Duggar and Stewart (9) studied the sterile fungus *Rhizoctonia Solani* as attacking several cultivated plants, including lettuce. They found this organism to be present on lettuce plants obtained from widely separated regions of the United States.

Chupp (6) referred to Dye's work of 1919 on a "bottom-rot" of lettuce caused by *Rhizoctonia Solani*. He says that it causes great losses in New York and the neighbouring states and adds that, whereas such a cabbage lettuce as Big Boston is more susceptible to attack in the field, the Iceberg variety (cos type) because of its upright habit is rarely affected.

Except for Flachs's work (10) published in 1927, there are no references to *Rhizoctonia* of lettuce in the current journals of the Continent of Europe. This worker found, in March 1926, near Munich a fungus which he called *R. violacea* (apparently *R. Solani*),* causing a collar-rot of lettuce. He saw the lesions of this fungus on 88 per cent. of the seeds tested in a germination experiment.

The first mention of *R. Solani* as the cause of damping-off in the British Isles was in 1921 when Bewley (4) published his paper on Damping-off and Foot-rot of Tomato Seedlings. Although this fungus is repeatedly mentioned in the reports of the Ministry of Agriculture as causing a considerable amount of damping-off of tomato seedlings, it is not mentioned in this connection as affecting lettuce.

In the Ministry reports just referred to there is only one reference to damping-off of lettuce (Spring, 1929), the causal organism being stated to be *Pythium de Baryanum*.

C. ISOLATION AND INFECTION METHODS.

For the purpose of isolation work, lettuce seedlings of various ages suffering from damping-off and from stem- and leaf-rot were collected during the Winter of 1929-30 from frames and greenhouses at a farm near Slough and at the Imperial College of Science Biological Station, Slough. These were carefully washed with tap-water to remove all dirt, then with a solution (1:1,000) of mercuric chloride for a few seconds and finally rinsed several times in sterilized water. Each seedling was then dried by pressing between sterilized filter paper and then laid on the surface of a plain agar plate. In twenty-four hours copious hyphal growth was given out (Plate I, Fig. 3) and a transfer was then made to tubes of oatmeal agar. When the object was to identify the fungus and not to obtain it in culture, the agar plate could be replaced by a thin film of sterile water.

The method of inoculation adopted was to sow lettuce seeds or to plant young seedlings in sterilized soil which had been inoculated with the fungus concerned. Both chemical and heat methods of sterilizing the soil were tried.

Tests with formalin (8 litres of 2 per cent. solution added to 5 cubic feet of wet soil) showed that this treatment was effective, but troublesome in that the removal of all traces of the chemical involved a great waste of time. In practice one could not be sure that the soil was safe for planting without growing a trial crop of seedlings in it before inoculating with the fungus. The slightest trace of formalin in the soil caused root poisoning, characterized by browning of the root especially at the root cap region. The method was therefore discarded in favour of the heat method.

For heat sterilization two methods were tried: steaming the soil in pots (3 ins. high by 2½ ins. internal diameter) for one hour and autoclaving at 120° C.

* Comment in abstract given in Review of Applied Mycology, 6, p. 651, 1927.

for twenty minutes. Both methods gave satisfactory results but the latter was preferred. The treated soil was then well watered, allowing the excess water to drain, and left exposed in the laboratory for three days before inoculation. Each pot was then inoculated with one culture tube of the fungus to be tested. This was well mixed up with the soil. Seeds were then sown or seedlings planted a few days after inoculation.

It should be added that soils, whether sterilized by heat or by formalin, favoured fungal growth. In an experiment with steam-sterilized wet soil inoculated with *R. Solani* (strain from lettuce) and incubated at 8° C., the fungus grew so luxuriantly as to form on the surface of the soil a thick cottony layer which extended up the inner and down the outer side of the pot. Even in wet uninoculated heat-sterilized soil such fungi as *Penicillium* sp. formed copious growths over the surface of the soil.

D. SUMMARY ACCOUNT OF FUNGI ISOLATED FROM LETTUCE.

During the Winter and Spring months of 1929-30, isolations were made from eighty-nine lettuce seedlings growing in frames or somewhat older plants in cold greenhouses. From all but three of these the fungus *Corticium* (*Rhizoctonia*) *Solani* developed, in nearly every case in pure culture. The affected plants showed damping-off, or rotting of the leaves or lesions on the stems. The three plants which failed to yield the *Rhizoctonia* showed rotting of the stem and root. From two of these the fungus *Fusarium culmorum* was isolated, and from the remaining one *Cylindrocarpon radiculicola*.

It is clear that the most frequently occurring fungus is *R. Solani*. All the cultures of this fungus obtained in this test and in tests carried out from time to time throughout the course of this work have proved to be identical. On the other hand, a strain of *R. Solani* isolated from a tomato plant growing in a hot greenhouse was distinctly different, both in manner of growth and in physiological and pathological relationships.

A series of isolations was also made from damped-off lettuce seedlings growing in a variety of soils under warm conditions. For this purpose, seeds of the lettuce variety Trocadero were sown in December 1929 in pots of soil from a variety of sources—Kew Gardens, Chelsea Physic Garden, the Biological Field Station, Slough, and a farm near Slough—and kept in a heated greenhouse. In this case and from all the soils used, species of *Pythium* were the organisms most commonly isolated from damped-off seedlings—viz. in approximately two-thirds of the plants examined. *Cylindrocarpon radiculicola* occurred also rather frequently (20 per cent. of the plants) and species of *Fusarium* occasionally. *Rhizoctonia Solani*, which was the dominant fungus isolated from seedlings which had damped-off under colder conditions, was not met with in a single instance.

The most important of these fungi are obviously *Rhizoctonia Solani* and *Pythium*. As regards *Fusarium culmorum* and *Cylindrocarpon radicicola* one notes that both occurred in the two sets of isolation experiments. *Cylindrocarpon radicicola* in particular was only isolated from seedlings which had grown in soil from Kew. Bearing in mind the known associations of these two organisms with root diseases of certain plants, one was inclined to attach some importance to their occurrence on lettuce. Infection experiments with both, however, gave negative results, so for the time being they may be looked upon as accidental. The other fungi which appeared from time to time (species of *Phoma*, *Eidamia*, *Acrothecium*, etc.) were considered to be unimportant, being probably mere saprophytes.

E. FACTORS INFLUENCING DAMPING-OFF.

The general view regarding the effect of environment on the incidence of damping-off diseases is that they are favoured by such factors as excessive soil moisture, high air humidity, low illumination, overcrowding (perhaps acting through the preceding factor), heavy texture and high organic content of soil. The effect of temperature varies with the particular damping-off fungus. The relation of a number of these factors to the incidence of damping-off has been tested in the course of this work.

(a) Soil Humidity.

In one experiment a large sample of medium loam soil was steam-sterilized in the usual way, and after some days divided into four portions. Three of these were heavily inoculated with the fungi (1) *Rhizoctonia Solani* (strain from lettuce), (2) *R. Solani* (strain from tomato), (3) *Pythium* sp. from lettuce, respectively, the fourth remaining uninoculated as a control.

The batches of soil were kept wet in order to allow the fungi to penetrate the soil thoroughly. After some time (actually $3\frac{1}{2}$ months) the soils were dried down to air-dryness, the remaining hygroscopic moisture being determined as 2.75 per cent. The water-holding capacity of this soil was found by Hilgard's method (14) to be 42.5 per cent. Water was accordingly added to the dry soil to make up a series of saturations of 100, 90, 80, 70, 60, 50, 40, 30 and 20 per cent.

Weighed quantities of the soils so prepared were placed in glass jars. Each jar was covered with a damp filter paper held in place by means of a Petri dish lid. The conditions were therefore such as to give a range of soil moisture, but in all cases a more or less saturated atmosphere. During the course of the experiment moisture in the filter paper covers was frequently renewed and it was found that there was no appreciable loss of water from the soils.

In each of these jars a hundred uniform Trocadero seedlings (approximately two days old) were carefully planted, the radicles being inserted into small

prepared holes. The object of using seedlings in place of seeds was twofold : first to obviate the irregularity of results arising from the presence of non-viable seeds, and second to overcome the difficulty that perhaps seeds would not germinate at the lower soil humidities or, if they did, would do so very slowly.

The jars were kept at laboratory temperature under ordinary conditions of reduced illumination. The data shown in Table I are the averages obtained in two concordant experiments of this kind. The figures give the percentage of seedlings which had damped-off in eleven days.

TABLE I.

Fungus.	Percentage of damping-off in each of the series of soil saturation.								
	20%	30%	40%	50%	60%	70%	80%	90%	100%
<i>Pythium</i> sp.	12	39	37	53	62	73	74	34	10
<i>R. Solani</i> . Strain from lettuce . .	15	42	58	62	81	85	86	70	42
<i>R. Solani</i> . Strain from tomato . .	90	89	80	82	76	72	71	66	58
Control	0	0	0	0	0	0	0	0	0

It is clearly seen that *Pythium* and the lettuce strain of *R. Solani* behave similarly, namely that there is a maximum of attack at 70-80 per cent. of soil saturation with a definite fall on either side. The curve given by the tomato strain of *R. Solani* is quite different, as it continues to rise as one proceeds from 80 per cent. of saturation to lower moistures.

The difference shown between the two *Rhizoctonia* strains in their response to soil moisture was so striking that a further test was carried out under somewhat more controlled conditions. Twenty-five seedlings in this case were planted in shallow earthenware dishes containing soil adjusted to various degrees of wetness and placed over water in closed desiccators. The results of this experiment after thirteen days are shown in Fig. 1.

The experiment was again repeated under similar conditions with the results shown in Fig. 2.

One may state, therefore, that under the conditions of a more or less saturated atmosphere the optima for damping-off by the tomato and lettuce strain of *R. Solani* are 30 per cent. and 80-90 per cent. respectively.

The occurrence of damping-off at low soil moistures may appear surprising, but other observations bear out this result. Thus during the Winter, 1930-1, severe damping-off (75 per cent.) occurred in late Autumn-sown lettuce in cold frames (Plate I, Figs. 1 and 2), the soil of which contained only 19 per cent. of moisture at the time when damping-off was actively progressing.

Damping-off of Lettuce

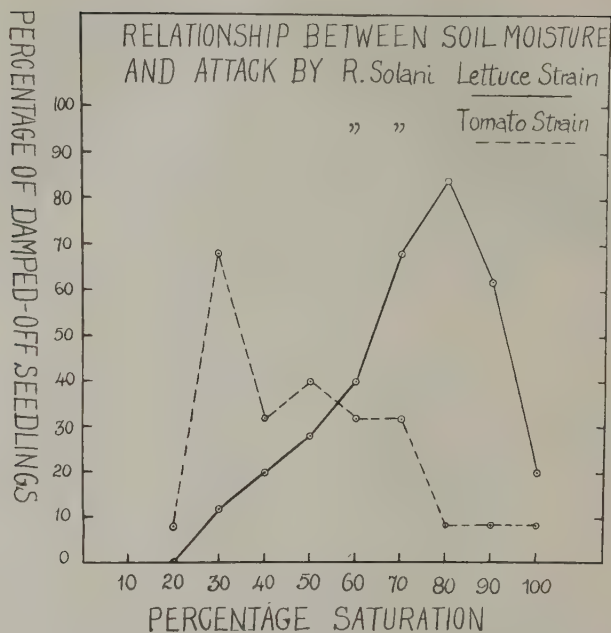


FIG. 1.

Effect of soil humidity on attack by two strains of *Rhizoctonia Solani*.

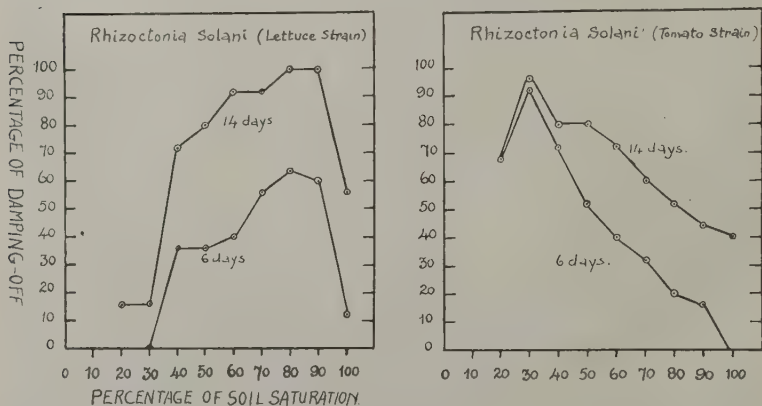


FIG. 2.

Comparative behaviour of two strains of *Rhizoctonia Solani* in soils of different water content.

This is in agreement with Walker's (19) statement that any soil moisture at which cotton plants will grow is sufficient for infection by *R. Solani*, given favourable soil temperature conditions.

An unexpected feature shown by all the curves is the reduced amount of attack shown at full saturation as compared with that at lower soil moistures. This is most marked in the case of *Pythium*, as may be seen from Table I.

In opposition to this result was the general experience of experiments previously carried out in which no difficulty was met with in producing 100 per cent. damping-off by sowing seeds in saturated freshly inoculated soil. It will be noted that in the experiments to which Table I and Figs. 1 and 2 refer the soil used was inoculated and then dried down preparatory to adjustment of its water content. Also seedlings and not seeds were used.

A further experiment was carried out as follows. A sample of soil was inoculated with *Pythium*, dried down and adjusted to a range of soil moistures in the way already described. Duplicate jars were set up for the range of

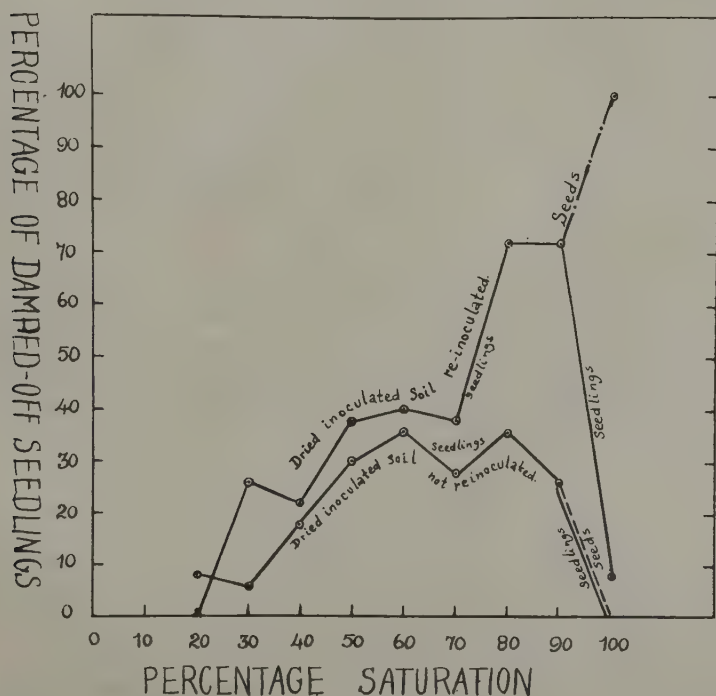


FIG. 3.

Effect of soil humidity on attack by *Pythium* sp. of lettuce seedlings.

humidity 20-90 per cent. One set was planted with lettuce seedlings without further treatment, the other was again inoculated before the seedlings were planted. Four further jars were fully saturated and set up as follows :—

- | | | |
|----|--------------------|---------------------|
| 1— | not re-inoculated— | seedlings planted. |
| 2 | „ „ | seeds sown. |
| 3— | re-inoculated | —seedlings planted. |
| 4 | „ | seeds sown. |

The amount of damping-off is shown in Fig. 3.

These results suggest that the apparent inconsistency observed is due to differences in the methods of experiment and in particular that there is a great difference between the behaviour of seeds and that of seedlings in saturated freshly inoculated soil. It may be added that in such tests with seeds the great majority of the latter are killed at the incipient stage of germination. The cause of the difference is not clear and requires further experimentation.

Incidentally it may be noted that in addition to the higher percentage of attack in soil freshly inoculated with *Pythium*, this fungus under these conditions frequently caused root-rot. This phase of attack was only occasionally noticed in inoculated soil which had been dried down. The first indication of an attack of the roots is when the root hairs lose their turgidity, become yellow and shrivel up. This is followed by the discoloration and softening of the root itself. Turning yellow, it becomes orange, then orange red, in colour, at which stage it becomes so soft as to disintegrate away. (Plate I, Fig. 4.)

It should be added that at lower soil humidity for the lettuce strain of *R. Solani* and for *Pythium*, and at higher soil saturations for the tomato strain of *R. Solani*, attack in many cases did not go beyond the formation of reddish brown spots on the surface of the stem. Thus *R. Solani* may succeed in forming, on the surface of the stem, a cushion which does not go any further. Except for the discoloration of the epidermis round this cushion no damping-off could be seen.

The time taken by damping-off to appear is least at the optimum moisture for attack. Thus in one experiment damping-off due to the tomato strain of *R. Solani* developed after five days in soils of 20-80 per cent. relative saturation, whereas it did not show until five days later in soils of 90 per cent. and 100 per cent. saturation.

Again, whereas at lower soil moistures in the cases of *Pythium* and the lettuce strain of *R. Solani* attack is strictly at soil-level, at higher humidities it is higher up the stem. Thus it often occurs half-way up the stem and, in saturated soil, it may even be seen just below the cotyledons.

(b) *High Air Humidity.*

It has been suggested by several workers that atmospheric humidity plays an important role in damping-off. Thus Atkinson in 1895 (2) concluded that damping-off is favoured by a humid atmosphere and by lack of ventilation. Chupp (6) in 1925 stated that damping-off is found in greenhouses or cold frames in which poor ventilation permits a high humidity in the air. Gadd (11) in 1928 states a similar conclusion.

For the purpose of studying the effect of atmospheric humidity on damping-off, one would require elaborate apparatus unavailable to the writer, who was, however, able to obtain from a series of rough experiments results that cast some light on this matter.

In one experiment a batch of soil was divided into two lots which were adjusted to 40 per cent. and 80 per cent. of saturation respectively. A series of shallow dishes were then filled with these soils and each dish planted with twenty-five lettuce seedlings (two days old). All the dishes were then kept for four days in a saturated atmosphere at room temperature, by which time damping-off had just begun. The damped-off seedlings were pulled out and the dishes then set up in desiccators over a series of sulphuric acid-water mixtures to give a range of air humidities. The daily loss of water from the dishes was determined by weighing and was compensated by adding the necessary quantity to the soil without wetting the seedlings. The strength of the sulphuric acid was also adjusted from day to day.

The number of plants which subsequently damped-off in seven days is given in Table II.

TABLE II.

Percentage Saturation of Atmosphere.	Pots with 40% soil moisture.		Pots with 80% soil moisture.	
	Total No. of plants.	No. of damped-off plants.	Total No. of plants.	No. of damped-off plants.
5.1	25	2	23	7
12.9	25	1	24	3
20.0	23	1	24	9
30.0	25	7	25	3
40.0	24	4	24	13
50.0	25	4	25	5
70.0	25	4	25	5
100.0	22	5	24	6

In spite of the irregularity of the figures, the table shows that in neither case did the driest atmosphere used completely stop damping-off. Thus while high humidity in the atmosphere may favour damping-off, it appears that even a high degree of drying in the atmosphere is insufficient to stop it.

One may summarize the effects of soil and air humidities as follows :—

1. Under conditions of a more or less saturated atmosphere the optimal soil moisture for attack by the lettuce and tomato strains of *R. Solani* is 80-90 per cent. and 30 per cent. respectively.

2. Although in the case of both fungi there is less damping-off at full soil saturation, it is nevertheless considerable (about 40 per cent.).

3. In inoculated soil which has been dried down the optimum for attack of *Pythium* is in soil with 80 per cent. moisture, with a sharp drop at higher concentrations in the case of seedlings. A hundred per cent. of seeds sown on fully saturated freshly inoculated soil damped-off, the majority at incipient germination.

4. Damping-off may take place in comparatively dry soils (20 per cent. saturated). This is especially noticeable with the strain of *Rhizoctonia* from tomato.

5. Once damping-off has begun, it will continue under comparatively dry air conditions. Thus, while it may be favoured by high atmospheric humidity, a high degree of dryness in the atmosphere is insufficient to stop it.

(c) *Temperature.*

The question of temperature as an important factor in attack by damping-off fungi has long been the subject of discussion by many workers. The popular view has predominantly been in favour of high temperatures at least as regards *Pythium*. In the case of *R. Solani*, however, different views have been held, some workers suggesting low and others high temperatures. Thus Atkinson (2) in 1895 stated that damping-off is favoured by high temperature. Balls (3) in 1905 held the opposite view, that lower temperature favoured "sore-shin" of cotton in Egypt. This disease disappears with the advent of hot weather. Balls actually found that, whereas infection took place at 20° C., it did not do so at 33° C.

Walker (19) in 1928 agreed with Balls up to a point. He found that the optimum soil temperature for attack of sore-shin ranged between 17° and 23° C., and that the maximum was 34° C. He failed to get the minimum because of the non-germination of cotton seeds below 15° C.

Hemmi (13) in a series of carefully controlled experiments showed that both *Pythium* and *R. Solani* attacked cress seedlings over the whole range of temperatures tested (10-30° C.). The former was the less active at temperatures below 20° C. but more active above 24° C. Both fungi caused great damage at temperatures between 17° and 26° C.

The effect of temperature was tested in a series of experiments in which seeds were sown on the surface of saturated inoculated soil in pots, covered with

wet filter paper and incubated in the dark at 8°, 15°, 20°, 30° and 35° C., four pots being used for each temperature.

Under these conditions very severe damping-off (approximately 100 per cent.) was caused by *Pythium* sp. over the whole range of temperature used. The difference in the behaviour of the two strains of *Rhizoctonia* was very striking, as is illustrated in Fig. 4.

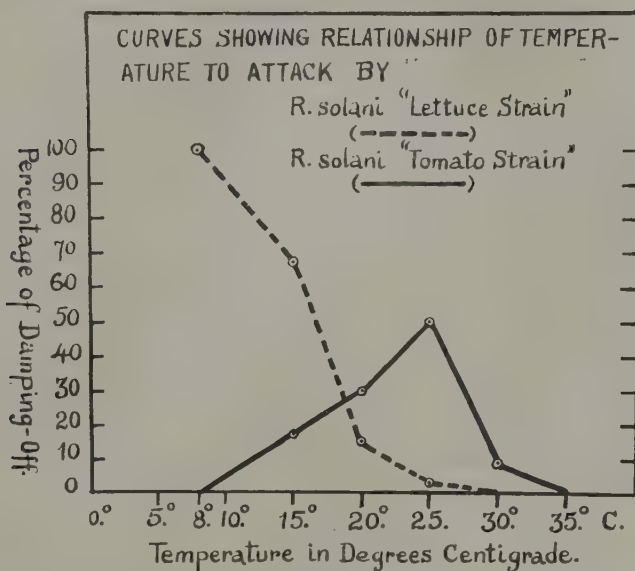


FIG. 4.

Effect of temperature on attack by two strains of *Rhizoctonia Solani*.

It is seen that whereas the optimum temperature for attack by the lettuce strain of *Rhizoctonia* is not higher than 8°, that of the tomato strain lies in the neighbourhood of 25°. The cardinal points for these fungi, as determined by growth on artificial media, are interesting in this connection and are as follows :—

<i>R. Solani</i> (lettuce)	..	Opt. 22°	Max. 30°
„ (tomato)	..	„ 29°	„ 35°
<i>Pythium</i> sp.	..	„ 30°	„ 35°

(d) Soil Composition.

The effect of soil composition on attack by *R. Solani* attracted the writer's attention inasmuch as, while no difficulty was experienced in getting a very high percentage of attack in loam soil, a very low one was obtained in sand.

Experiments to determine the amount of attack in steam-sterilized soils of different mixtures of loam, sand and leaf mould inoculated with the "lettuce" strain of *R. Solani* gave the results shown in Table III. The figures are calculated as percentages of the actual number of seedlings germinated from 100 seeds sown.

TABLE III.

Nature of Soil used.	Experiment 1. Over a period of fourteen days.	Experiment 2. Over a period of seven days.
	% damping-off.	% damping-off.
Leaf mould	76	78
Loam from field	74	41
Loam from cold frame	70	40
2 parts loam + 1 part sand	60	21
1 part loam + 1 part sand	61	37
2 parts loam + 1 part sand + 1 part leaf mould	58	33
1 part loam + 1 part sand + 1 part leaf mould	56	22
Sand in saucers	2	6

It is clear that whilst the highest percentage of attack is in leaf mould soil the lowest is in sand. Loam and various soil mixtures gave intermediate figures. This result is in agreement with Müller's (16) statement that clay soil containing humus is most favourable for *Rhizoctonia*.

A similar set of experiments with *Pythium* gave approximately 100 per cent. of attack in all cases.

F. METHOD OF PENETRATION AND ATTACK.

The first attempt to study the penetration of a *Rhizoctonia* was in 1891 when Prillieux (17) determined the nature of the "corps miliaires" of *R. violacea* which he found to be microsclerotial bodies serving as infection cushions, from which strands of hyphae penetrate the host. Duggar (8) later confirmed Prillieux's observation of the presence of conspicuous infection cushions on the root-investing mycelium of *R. violacea* on a number of plants, but found nothing comparable to these in *R. Solani*, though he considered that in the case of potato tubers the sclerotia formed by the latter fungus might serve as foci of infection. In the same year Drayton (7) studied stained sections of potato with *R. Solani* lesions. He found that from three to six cortical cell layers from the surface of the lesion were filled with closely compacted hyphae, which he concluded to be *Rhizoctonia* hyphae as they were short, swollen, and constricted at the junction of the cells. He attributed the brown colour of the lesion to them. In contrast with the latter statement Duggar (8) found that hyphae of *R. Solani* inside the host were hyaline and only differed from those outside by their somewhat narrower diameter.

Matsumoto (15) studied in detail the penetration of *R. Solani* in artificially infected leaves of Azuki bean, broad bean and Cameria and on stems of cucumber. He found that *Rhizoctonia* hyphae have a tendency to develop densely intermingled hyphal branches closely in contact with the host surface before they penetrate the cuticle. He showed that penetration of the epidermis and passage from cell to cell are effected by peg-like hyphae and that the hyphae grow in the host tissue in various directions, being mostly intercellular.

With regard to the mode of attack of *Pythium de Baryanum*, Butler (5) says: "The hyphae enter directly across any cell of the hypocotyl or the upper part of the roots across any cell of the epidermis. Here their development is rapid. They bore through and between the cells, quickly infecting the whole of the cortex in the neighbourhood of the point where they enter." Later, in 1919, Hawkins and Harvey (12) studied the penetration of potato cell walls by this fungus and produced evidence supporting the theory of mechanical penetration. They described and figured the appearance of hyphae penetrating the cell wall comparable to that seen by Matsumoto in the case of *R. Solani*.

The writer has studied the penetration of the *Rhizoctonia* strains from lettuce and from tomato and of *Pythium* as they attacked five-days-old lettuce seedlings growing in artificially infected soil. The affected seedlings were fixed in Farmer's solution and microtome sections (8 μ thick) made in longitudinal or transverse directions. These were stained in 2 per cent. cotton blue in lactophenol for five minutes, well washed in water and differentiated in Delafield's haematoxylin for two minutes. In properly stained preparations the host tissue appears violet pink in contrast to the Prussian blue of the fungal hyphae.

(a) *Rhizoctonia Solani*, strain from lettuce.

As soon as the hyphae of *Rhizoctonia*, already present in the form of a weft on the soil surface, come in contact with the host they give a side branch which buds off in a more or less dichotomous manner short swollen cells. This process goes on till a wart-like spongy microsclerotium (Plate I, Fig. 5), at first hyaline but later becoming light brown in colour, is formed on the surface of the host. Though spongy in texture, this structure would appear to be analogous to the "corps miliaire" of *R. violacea* in that it is an infection cushion.

The first indication of penetration is the appearance of a small water-soaked spot just underneath this cushion. This extends deeper into the host tissue till it reaches the vascular elements, after which it spreads along the axis up and sometimes up and down the stem. The attacked tissue, besides becoming water-soaked, assumes an olivaceous colour due to staining of the cell wall. The water-soaked area may extend one centimetre or so along the stem by the time the seedling collapses and falls on the ground.

Seedlings in the rough leaf stage show, when attacked, characteristic flagging of the leaves—whence the name “Drop” given by certain growers—accompanied by loss of lustre. Although the entire cortex of such plants shows a soft brown-rot extending in most cases to the basal parts of the leaf, the vascular elements, especially in the somewhat older seedlings, remain intact for some time, connecting the aerial part of the plant with the healthy root.

When older seedlings with stouter stems are attacked, the fungus may be localized in lesions encircling half or all the stem. Such necrotic lesions differ from those due to *Botrytis* in their darker reddish colour and in the absence of conidia of that fungus. Plate I, Fig. 6 shows a transverse section of such a lesion where the attack extended through the cortex to the vascular bundles.

Occasionally the stems of still older seedlings may be healthy while the leaves touching the ground may be affected. The attack, starting at the midrib, soon extends to the whole blade which may become soft-rotted with red discoloured veins (Plate I, Fig. 7). This phase of the disease appears to be similar to, if not identical with, that known in America as “Bottom-Rot”. Such leaf-rot could only be distinguished from that caused by *Botrytis cinerea* by the lighter colour of the lesion, by the absence of conidia of the latter fungus, and by the presence of typical *R. Solani* hyphae emerging from the surface and from the glandular hairs of the leaves.

As to the method of penetration, as soon as the sclerotial cushion is formed the short swollen cells appressed to the cuticle produce peg-like outgrowths which bore their way through the wall, after which they resume their normal thickness. Numerous such penetrations take place below each cushion. The hyphae are intercellular and only very occasionally intracellular (Plate 2, Fig. 8). They infect the whole tissue of the plant, cortex, phloem and wood vessels. They are more or less uniform in diameter, the average measurement being 7μ , and rich in protoplasmic contents and always hyaline, and are divided by septa into segments $24\cdot4$ to $81\cdot2\mu$ long (average 53μ). They branch in the host cells in the typical *Rhizoctonia* fashion (Plate 2, Fig. 8) in that the young hypha is given off at a right angle but soon inclines to the direction of growth of the parent hypha, sometimes running alongside the latter. Disorganization of the tissue is only noticeable in the region actually occupied by the hyphae, i.e. there is no evidence of any action in advance of the hyphal growth.

(b) *Rhizoctonia Solani*, strain from tomato.

This strain agrees in its method of penetration and mode of attack with that from lettuce. It differs, however, in the more diffused and mealy-looking infection cushion. Moreover, the advance of the fungus in the host tissue is mainly intracellular and the hyphae are narrower. As many as thirteen of these were seen in one single host cell (Plate II, Fig. 8). There is evidence of lethal

action in advance of penetration in the presence of collapsed disorganized tissue beyond the region of the fungus (Plate 2, Fig. 9).

(c) *Pythium* sp. from lettuce seedlings.

This fungus agrees with both strains of *Rhizoctonia* in that the hyphae penetrate by peg-like processes. It differs, however, in that the hyphae enter singly and directly across the epidermis, boring between and through the cells. They are mainly intracellular (as in the *Rhizoctonia* strain from tomato) and only very occasionally intercellular. The hyphae may penetrate from cell to cell at any point of the wall they strike, irrespective of position, whether in the centre or at the corner, obliquely or at right angles (Plate II, Fig. 10). The hyphae in the host tissue are not uniform in diameter, being thinner (3μ broad) in the long etiolated cells of the stem and stouter (4μ broad) in the short cells of the hypocotyl nearer the cotyledons. They are non-septate, rich in protoplasmic contents and stain less deeply with cotton blue than the two strains of *Rhizoctonia*. The penetrated cell wall is discoloured with a brownish yellow substance which is more intensified near the region of vigorous growth of the seedling. Such discoloured cell walls do not stain with haematoxylin.

G. SUMMARY.

1. Several fungi have been isolated from damped-off seedlings of lettuce of various ages, the most important being *Rhizoctonia Solani* and *Pythium*, the first from plants growing at low, and the second from those at high, temperatures. A strain of *R. Solani* isolated from the rotted collar of a tomato plant growing in a hot greenhouse was found to be highly pathogenic to lettuce.

2. The relationship of soil and air humidity to damping-off is summarized in Section E, pages 262-70.

As to the effect of temperature on damping-off, *Pythium* gave 100 per cent. attack at all temperatures from 8° to 30° C. While the strain of *R. Solani* from lettuce is a low temperature parasite with an optimum for attack not higher than 8° C., that from the tomato is a high temperature one with an optimum at 25° C.

3. While the percentage of attack by the lettuce strain of *R. Solani* is high in leaf mould and in loam soils, it is low in sand and intermediate though still high in mixtures of these soils. Approximately 100 per cent. attack is obtained in all soil mixtures inoculated with *Pythium*.

4. The strains of *R. Solani* from lettuce and from tomato both attack by means of a spongy infection cushion below which numerous penetrations take place. The infection cushion is wart-like in the lettuce strain, and more diffused in the tomato strain, of *R. Solani*. *Pythium*, on the other hand, penetrates the epidermis by single hyphae.

Pythium and both strains of *R. Solani* penetrate the cuticle by peg-like hyphal outgrowths which bore their way through the wall after which they resume their normal thickness.

Whereas the hyphae of the lettuce strain of *R. Solani* in the host cells are mainly intercellular, those of the tomato strain and of *Pythium* are mainly intracellular.

There is no evidence of any action in advance of the hyphal growth of the strain of *R. Solani* from lettuce and *Pythium*, but there is in the case of the tomato strain of the former. The brown colour of the water-soaked region in seedlings attacked by all three fungi is due to discoloration of the walls of the host cells.

The work described in this paper was carried out at the suggestion and under the direction of Professor W. Brown, to whom the author wishes here to express his thanks.

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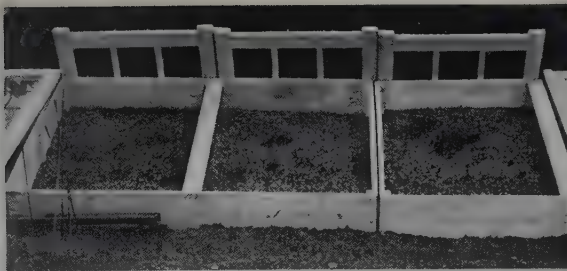


FIG. 1

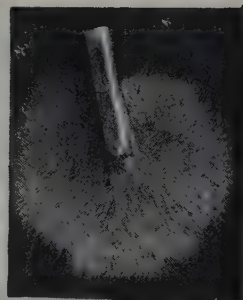


FIG. 3

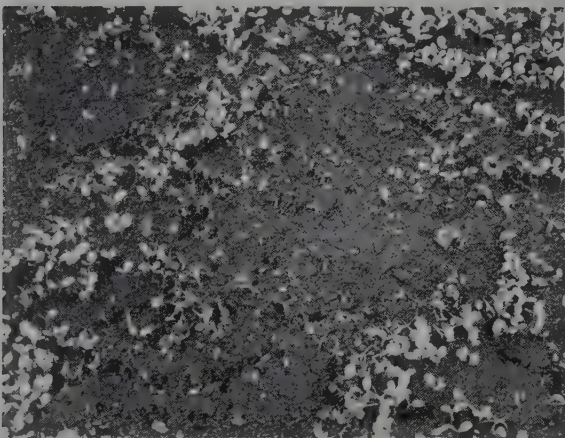


FIG. 2

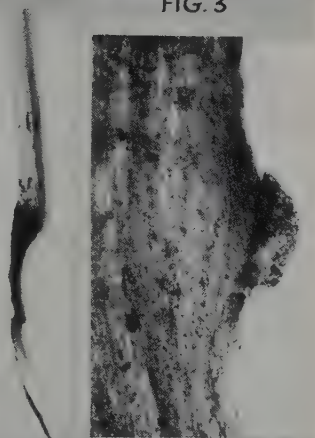


FIG. 4



FIG. 5

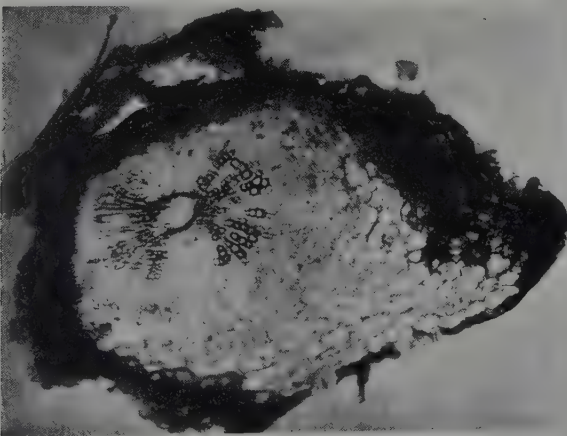


FIG. 6



FIG. 7

FIG. 1. Commercial frames showing severe damping-off due to *R. Solani* strain from lettuce. Note the patchy occurrence of the disease. FIG. 2. A closer view of patches in above frames laid bare by *R. Solani* (lettuce strain). FIG. 3. Growth of the tomato strain of *R. Solani* from an attacked tomato stem laid on agar for isolation (natural size). FIG. 4. Root-rot and damping-off of lettuce seedlings due to *Pythium* sp. (X approx. 3). FIG. 5. Infection cushion of *R. Solani* (lettuce strain) on lettuce stem (magnified). FIG. 6. Transverse section of a stem of lettuce seedling attacked by *R. Solani* showing extent of attack in the cortex (X approx. 150). FIG. 7. Lettuce leaves attacked by *R. Solani* (slightly magnified).



FIG. 8.

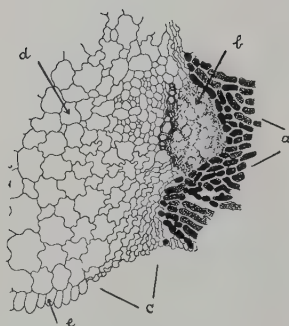


FIG. 9.

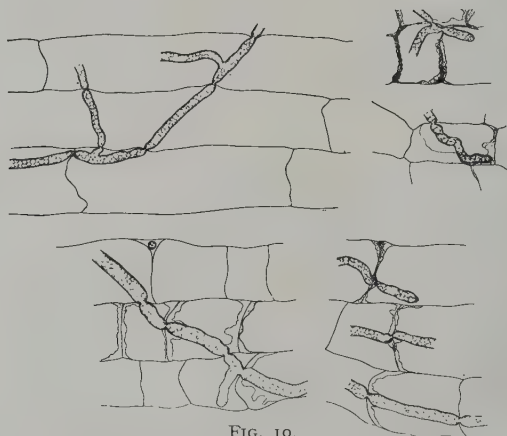


FIG. 10.

FIG. 8. 1-5: transverse sections of stem of lettuce seedlings showing method of attack by the lettuce strain of *R. Solani*; 6: longitudinal section of a similar seedling showing method of growth and branching of the lettuce strain of *R. Solani*; 7: transverse section of a similar stem showing the intracellular method of growth of the tomato strain of *R. Solani*-hyphae in cross sections in cells ($\times$ approx. 500). FIG. 9. Lettuce stem attacked by *R. Solani* (tomato strain) showing (a) region invaded by fungus, (b) disintegrated region in advance of fungus, (c) region of collapsed and disintegrated cells free from fungus, (d) healthy tissue, (e) healthy epidermis ($\times$ approx. 500). FIG. 10. Method of cell penetration and attack by *Pythium* sp. on lettuce seedlings in longitudinal sections (highly magnified).

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I. EXPLANATION OF PLATES.

Figs. 8-10 are camera lucida drawings, the remainder are photographs.

(Received 4/4/33.)

CHERRY STOCKS AT EAST MALLING

I. STOCKS FOR MORELLO CHERRIES

By N. H. GRUBB

I. ORIGIN AND SCOPE OF THE INVESTIGATION.

The plant material used by fruit growers in laying out orchards and plantations provided, in 1913, the chief items on the programme of the newly established Research Station at East Malling. The rootstocks on which the tree fruits are "worked" inevitably occupied a prominent place; and since East Malling is in one of the cherry growing areas of Kent, it was early decided that cherry rootstocks should be included.

Ten sets of cherry stocks, including representatives of all classes known to be in use in Europe, were obtained from nurserymen at the end of 1913. Of the ten, five proved to belong to the sweet cherry species, *Prunus Avium*; four of these were received under the name "Common Cherry" and one as "Black Mazzard". Three sets belonged to the Mahaleb cherry species, *P. Mahaleb*; these were all called "Mahaleb" by the senders. The remaining two sets belonged to the acid cherry species, *P. Cerasus*; one was received under the name "*Prunus austera*" and the other as "Common Cherry".

Additional sets of stocks were later obtained from nurserymen and others. In 1917 a nursery firm sent two sets, under the names "Common" and "Mazzard"; both of these proved to belong to *P. Avium*.*

In addition, batches of seedlings have been raised at East Malling from seed obtained from various sources; the majority, belonging to both *P. Avium* and *P. Mahaleb*, were from open pollinated seeds collected from cherry stocks growing unworked at East Malling. One batch was raised from seed of *P. Cerasus* growing wild near Folkestone.

The cherry stocks obtained from nurserymen appeared to be mostly seedlings. One or two of the senders claimed that their sweet cherry stocks were suckers from wild trees: whilst this may have been so, the variation even in these sets indicated that each probably came from a different parent tree. There is no doubt that the three lots of Mahaleb stocks and the two of acid cherry received in 1913 were seedlings.

More recently two sets of sweet cherry stocks and two of acid cherry have been received which are not seedlings. The sweet cherries came from Worcestershire under the names "White-barked Mazzard" and "Black-barked Mazzard";

* Since the terms "Common" and "Mazzard" have both been used for sweet cherry stocks, whilst "Common" has also been used (at least once) for acid cherry stocks, it seems best to the writer to use only the terms "sweet cherry" and "acid cherry" throughout.

they were evidently suckers, the latter in all probability from one parent tree. The two acid cherry stocks, said to be obtained as suckers from cultivated trees, were the "Stockton Morello" from California and the "Kentish" from New Zealand.

Although the great majority of the cherry stocks so far received have been seedlings, there is no doubt that the wild cherries dug from the woods, commonly used as stocks by cherry tree raisers in England, are often suckers from large trees. They are probably more or less mixed with natural seedlings.

No other species of *Prunus* appear to have been commercially used as cherry stocks in Europe. In North America and Japan, however, several other species have been tried, some with considerable success; one or two are in regular commercial use. A discussion of these species may be found in *Cherries of New York*.

It would appear from our experience, as well as from the rather limited literature of the subject, that the great majority of the cherry stocks commercially used in the world are seedlings; the only exceptions known to us are those already cited, and the regular use, by certain nurserymen in Australia and New Zealand, of sweet cherry stocks raised from root cuttings.

In view of these facts, it seemed necessary to try to find answers to three questions:—(a) Can cherry stocks in general be propagated vegetatively? (b) If they can, will there be a large enough improvement in the standard of tree performance to make it worth while? (c) Regardless of method of propagation, do the three species of *Prunus* commercially used as stocks in Europe influence the scion differently?

This report analyses the data so far collected at East Malling from cherry stocks and stock trials, in so far as they refer to the Morello scion.

2. CAN CHERRY STOCKS BE PROPAGATED VEGETATIVELY?

Very few references to the vegetative propagation of cherry stocks occur in cherry literature. No published account of any investigation of the subject has been traced. General statements are, however, fairly common, such as:—"Cherries, in common with other stone fruits, grow readily from root cuttings" (1). "The Mazzard is almost always grown from seed for stocks, though suckers are occasionally used—a poor practice" (2). "Though it (i.e. the Mahaleb cherry) may easily be grown from layers, cuttings, or suckers" (2). Neither of these writers indicates the source of his information. Probably few if any systematic attempts at vegetative propagation of cherry stocks had been made until the work here reported was begun.

Each set of cherry stocks collected in 1913 was divided into two lots, one allowed to grow naturally, to show individual characteristics, and the other layered for propagation. Later sets as they were received were planted in the main for layering.

Two or three years' work showed how readily several of the sweet cherry stocks rooted from layers. Longer experience has shown that a few sweet cherries habitually root as readily as any plum stocks ; the majority root moderately well, whilst a few can be rooted only with difficulty. The result appears to depend mainly on the individuality of the seedling layered. Sets of stocks from different sources showed considerable differences in the proportion which rooted freely ; but as the numbers layered were small, varying from 10 to 40, the differences are probably not significant.

From the three sets of Mahaleb stocks received in 1913, thirty-two plants were layered, for several successive years. Few showed any sign of rooting, except to a small extent from the two-year-old wood ; and even the best rooted gave a very small proportion of shoots with roots, all close to the base. Such methods as twisting and notching the layered shoots before they were covered with soil have been tried, but without any notable success.

Batches of seedlings raised from open pollinated seed of Mahaleb ripened at East Malling have given more promise. Fifty-five seedlings were layered ; of these, three were ultimately selected as rooting moderately well. Even of these, however, it is unusual to find as many as 50 per cent. of the shoots well rooted.

From the two sets of acid cherry stocks received in 1913, twenty-four plants were layered. After several years' trial, not one was found which would root freely enough to make it of even experimental value.

A small batch of seedlings raised from open pollinated seed of an acid cherry growing wild near Folkestone has proved more hopeful. Five seedlings survived long enough to be layered ; one of these has frequently produced 50 per cent. or more of rooted shoots, whilst another has usually rooted moderately well.

The " Stockton Morello " and New Zealand " Kentish " have not yet been tested long enough at East Malling to show whether they can be readily propagated by layering ; they are normally propagated from suckers. In addition to these, the Wye Morello or Morella, obtainable as suckers in Kent, has been layered for one year, and already shows signs of rooting more readily than most acid cherries.

Since Mahaleb and acid cherry seedlings proved to be difficult to propagate by layering, cuttings of various sorts were tried. Hard-wood cuttings have not so far given any success. Soft-wood cuttings under glass, with bottom heat, however, have given uniformly satisfactory results. Should any of these stocks prove to have commercial value, a method not prohibitive in cost could undoubtedly be found.

Sweet cherry stocks are in many cases readily propagated by means of root cuttings. Certain of the fruiting trees described below were first propagated in this way, and afterwards by layering. It is probable that certain individuals will grow from root cuttings more readily than others.

Root cuttings of Mahaleb stocks have been tested repeatedly without success. It has been found as a rule that neither hard-wood nor root cuttings of Mahaleb will even produce a callus ; though this, as is now known, is not a necessary preliminary to rooting. It is possible that here again a prolonged search would yield individuals capable of propagation by these methods.

Some measure of success has been met with in growing root cuttings of acid cherry stocks ; those tested so far, however, have been less satisfactory than the majority of sweet cherries.

Many sweet cherry seedlings, and probably all, can be propagated by means of suckers, when the root system becomes large enough to produce them. Most of the sweet cherry stocks now under trial have already begun to produce suckers ; some, at least when worked with Morello scions, produce many more than others.

The two acid cherry seedlings so far tested as stocks have also begun to sucker freely, one considerably more than the other. It has been noticed also that the wild acid cherry already mentioned seems to spread freely in the wild state by means of suckers.

The two Mahaleb seedlings tested as stocks have never, up to the eleventh year from grafting with Morello, produced a single sucker. The fruiting trees, from which the seed mentioned above was obtained, had also never produced a sucker up to the time of their removal. A grafted tree in the variety collection at East Malling, however, recently produced one sucker which proved to be Mahaleb ; but this was found to be growing from a broken root, and was therefore more properly a root cutting. The writer cannot remember ever having seen any other sucker from a Mahaleb stock. Tukey (3), however, illustrates what he describes as " a common sight in cherry orchards of New York State "—Mahaleb suckers growing from the roots of a dead cherry tree.

Many sweet cherry stocks, then, are easily propagated by layering ; other vegetative methods are possible and in fact are sometimes used ; but there is no reason to suppose that they would produce stocks more easily than layering.

The great majority of Mahaleb seedlings cannot be satisfactorily propagated by layering, hard-wood cuttings, root cuttings or suckers ; but they can be grown from soft-wood cuttings under glass.

Acid cherry seedlings behave similarly to Mahalebs, except that they can be obtained as suckers, and may sometimes be grown from root cuttings.

3. IS VEGETATIVE PROPAGATION WORTH WHILE ?

The attempt to find an answer to this question involved at the outset a study of the stocks themselves, their botanical and other characteristics, resistance to diseases, etc. If it could be shown that the seedling stocks of any one species were very uniform, there would be little reason to expect that the scions worked

on them would show any considerable variation, and vegetative propagation would not be worth while. But if the stocks of any species were found to vary considerably, it would be at least possible that they would influence the scion differently; if such influences were large in degree, vegetative propagation might become worth while in order to get a more uniform standard of tree performance. So far as is known to the writer, only one report of a similar examination of cherry seedlings has been published. Heimann (4) reports an extensive examination of Mahaleb cherry seedlings, raised from seed collected from fourteen widely different parent trees. Each family of seedlings closely resembled its parent; the families differed particularly in habit of growth and character of leaf. Heimann adds that similar differences exist amongst wild sweet cherries.

A. VARIATION OF CHERRY SEEDLINGS.

Of the collections of cherry stocks obtained from nurserymen in 1913, 170 individuals, belonging to eight different sets, were planted out for observation. They were allowed to grow naturally, unpruned except for the removal of broken and diseased wood. About 150, belonging to all three species, survived until the fruiting stage.

(i) SWEET CHERRY.

The five sets of sweet cherry stocks obtained from nurserymen had certain group characteristics; but there was in several respects wide variation within each set. One set, consisting of only nine trees, showed quite exceptional variation in vigour, habit of growth, time of blossoming and leafing, and fruit character. Another, consisting of forty-two trees, was distinctly less variable in vigour and time of bud breaking, but almost equally so in habit of growth and fruit character. A third set was almost uniformly late in bud breaking, but distinctly variable in other respects.

Whilst the variation in vigour was probably somewhat exaggerated by the crowded nature of the row of trees, this would not account for the variation in other respects, particularly in fruit character. Each set comprised trees having fruit with dark and colourless juice; many were very small and others of fair size; some were bitter and astringent and others sweet and pleasant flavoured; some were dry, with little flesh, whilst others were juicy and had much flesh and a small stone. Almost every variation in the fruit of named cherry varieties could be matched, on a smaller scale of sizes, from amongst these seedling stocks.

Seedling sweet cherry stocks, then, are very far from being uniform in any of the characteristics mentioned. Further observation has shown that they vary widely also in their resistance to disease and in the number of suckers thrown up by their roots, as well as in their readiness of rooting from layers.

(ii) MAHALEB.

Twenty-four stocks belonging to two of the three sets of Mahalebs obtained in 1913 were planted for observation ; all survived to the fruiting stage. One set showed somewhat more variation in vigour and habit than the other ; whilst in vigour neither set was as variable as the sweet cherry stocks, they were by no means uniform, and in other respects they varied widely. Two stocks out of the twenty-four were distinctly erect in habit, and lacked the very drooping low branches usually so characteristic of Mahalebs. One was exceptionally early in opening its blossoms and leaves, whilst others were later than the majority.

In fruit character, also, the variation was surprising. Whilst the majority had black fruit, a few were red when fully ripe and one was bright yellow, with only a faint tinge of red. The fruits varied greatly, also, in size, shape and edibility.

(iii) ACID CHERRY.

Twelve acid cherry seedlings, belonging to one of the sets obtained from nurserymen ("*Prunus austera*"), were planted for observation ; all survived for five or six years. They were found to be extraordinarily variable in every characteristic, much more so than any of the sweet cherry or Mahaleb collections. Eleven of the twelve were noted as being " more or less dwarf ", but the twelfth was more vigorous than many of the sweet cherries, and in fact more resembled a sweet than an acid cherry in leaf and growth. Since its fruit was moderately sweet, this seedling was probably a hybrid, coming properly in the " Duke " class.

The remaining eleven stocks, though all weaker in growth than any sweet or Mahaleb cherry in the row, varied enormously in vigour, habit, size, shape and pose of leaf, and number and thickness of shoots. Three or four of them never produced any blossoms up to the time of their removal, nine years from planting. Those that did blossom showed great differences, particularly in length of pedicel. Apart from the hybrid already mentioned, only two produced any fruit ; both had round, soft, acid fruit, one bright scarlet and the other pale red or pink.

More recently the writer has grown a few open pollinated seedlings of Morello in his garden until they were big enough for budding. Even at such an early stage there were notable differences in vigour, habit, and character of leaf ; but it seemed probable that the variation would never have been as great as amongst the seedlings just described.

Enough has been said to show that seedling cherry stocks of all three species, obtained from commercial sources, are very far from being uniform. Sweet cherries and Mahalebs are perhaps less variable than many batches of seedling apple and pear stocks ; but the variation is quite great enough to make extensive stock influences on the scion at least a possibility.

The fact that vegetatively propagated cherry stocks are very much more uniform than seedlings in the nursery has already been reported (5). Thus if seedling stocks produce a variable influence on the scion this cause of variation can be eliminated by the use of vegetative stocks.

B. ROOTSTOCK INFLUENCE WITHIN THE SPECIES.

Published references to rootstock influence amongst cherries are somewhat scanty, and are almost wholly confined to the comparative influence of stocks belonging to different botanical species. The only reference to the possibility of rootstock influence within the species which the writer has been able to find occurs in *Cherries of New York*. "Trees and fruit", says the author, "coming from the Mazzard used as a stock are very uniform, a fact easy to ascertain in New York, where this stock has been largely used for nearly a century" (2). The same author gives a very full discussion of the history (in America) of the use of Mahaleb stocks for cherries, and their influence on the scion compared with that of sweet cherry stocks; but he does not appear to mention the possibility that different Mahalebs might influence the scion differently.

Casual observation in English cherry orchards and plantations indicates that trees of all varieties are less variable than, for instance, bush apple trees on seedling stocks. For this there may be more than one reason. In the first place, the use, as stocks, of wild cherries dug from the woods is likely to reduce the variation of the trees, since many at least of these are suckers, and several may come from one tree. And further, in wild conditions, weak forms would be largely suppressed. Secondly, a larger proportion of weak stocks is likely to be eliminated in the nursery than in the case of apples, especially where cherry stocks are grafted "standard high". In a previous report (5), it was shown that seedling cherry stocks "run up" for high working in nurseries often take a long time to become tall enough; in the case reported, after four years' growth in place, only about 33 per cent. of the seedlings were tall enough. Unless the nursery were carried on for two or three years longer there would be a very large elimination of the weaker forms.

But neither of these explanations would account for a greater uniformity of bush cherry trees, e.g. Morello, on seedling stocks than of similar bush apple trees. It is probable that cherry seedlings, at least of sweet cherry and Mahaleb, are inherently less variable than most classes of apple seedlings. It has already been shown, however, that their variation is by no means inconsiderable. The data presented below indicate that they may have a more variable influence on the scion than casual observation would suggest.

A few layered cherry stocks were budded with Morello in the Summer of 1921 and a considerable number in each of the two following years. At the end of 1923 a few two-year-old Morellos and a number of yearlings were planted out;

a year later a further series of yearlings was added. These form the first three series of stock trial trees. The rootstocks represented in Series 1 were one sweet cherry variety and two Mahaleb varieties. In Series 2 the same three stocks were again represented, together with five other sweet cherry varieties; and a few trees on acid cherry stocks were also planted. The third series comprised trees on four sweet cherry varieties (one represented in the second series as a "control") and two acid cherry varieties.

A fourth series of yearling Morellos was planted out two years later still, at the end of 1926. The rootstocks here included were all sweet cherry varieties, two of which were represented in the third series, and one of these two also in the second. At the end of 1932, the four series of trees were therefore eleven, ten, nine and seven years from the bud respectively. All have been treated as bush trees, with a two-foot "leg".

The Morello variety used as scions was originally obtained as buds from a single wall tree known to bear high quality fruit. All the trees in the Morello stock trials have therefore been propagated from a single individual, and constitute a "clone". Whilst several different "Morellos" are undoubtedly grown commercially in England (often differing so little in botanical characteristics as to be almost indistinguishable), only one of them is represented in the trials here reported. The only possible cause of mixed scion varieties would be "bud sporting". Close watch has been kept for "sporting"; up to the present it does not appear to have occurred.

All four series of trees were planted before the technique of plot arrangement now in use had been fully developed. In the first three series, each group on one stock was planted in two places on the plot, with a symmetrical arrangement. In the fourth series, the groups were mostly planted in three or four places, arranged at random. Although it is not possible to calculate the probable effects of soil and position on the behaviour of the trees, the differences are in some respects so striking that they may nevertheless be regarded with considerable confidence. It may be remarked that results obtained in early rootstock trials with apples, in plots arranged symmetrically like the cherry stock trials here reported, have been confirmed in almost every detail by later trials arranged according to the latest technique of plot lay-out.

In Series 1 to 3 the unit was mostly eight trees on each stock; in Series 4 it varied from seven to thirteen. The total number of trees planted was 120 in Series 1 to 3 and 102 in Series 4.

The stock trials have more recently been extended to include two other acid cherry scion varieties—Kentish Red and a variety known to us as "Carnation", which may be wrongly named; and also three sweet cherry varieties—Early Rivers, Turkey Heart and Bigarreau de Schrecken. Since these trees are still too young to have given clear-cut results, it is not proposed to deal with

them here, except in so far as they already confirm or contradict the results with Morello scions.

In considering the results described below, readers should bear in mind the method of selection of the stock varieties. All, except three in the fourth series of trial trees, were selected solely because they rooted from layers more readily than those which were rejected. Characteristics which, if transmitted to the scion, might be useful, were not considered. (The three exceptions—all sweet cherry stocks—were raised by means of root cuttings from trees in the fruiting row already described. Two of them, 1/2 and 10/2, were selected as exceptionally vigorous specimens; the third, 2/3, was exceptionally weak. Table I, below, shows that this method of selection did not answer.)

It is therefore certain that a greater range of stock varieties would have yielded wider extremes of stock influence than any here described; and it is more than probable that such a range would also have shown influences in directions other than those so far discovered.

Although the range of influence of cherry stocks so far revealed is very much less than that amongst apples, such a range is not necessarily unattainable. "Paradise" apple stocks have been selected by many horticulturists in several countries, over a period of certainly more than a century. It would be too much to expect that such a range could be duplicated at one institution in a period of no more than seven or eight years, especially as the method of selection had in most cases no relation to possible stock influence.

(i) SWEET CHERRY STOCKS.

The trees worked on different sweet cherry stock varieties differ considerably in vigour, cropping, time of ripening, size of fruit, and some other characteristics. The symmetrical arrangement of those in the second and third series makes it possible that the differences, though distinct, may be in the main due to the effects of soil and position; they must therefore be regarded, by themselves, with suspicion. The younger trees of other scion varieties, however, are already showing differences in vigour, and since these in large measure confirm those shown by the Morello scions, the latter may be stated in general terms.

(a) *Vigour.*

The nine sweet cherry varieties represented as stocks in the second and third series of trees probably influence the Morello scion as follows:—(The numbers are those under which some of these stocks have already been distributed for trial.)

Weak	..	..	..	5/2, 5/4.
Medium	..	..	..	1/1, 2/2, 9/1.
Vigorous	..	..	..	2/1, 5/1, 12/4, 12/1.

The fourth series, including trees on ten sweet cherry stock varieties, has given a more clear-cut result. Table I gives a summary of the available measurements of tree size.

TABLE I.
*Size of Trees on Different Sweet Cherry Stocks.
Seven years old from the bud.*

Stock.	No. of Trees.	Area of cross section of stem, sq. cm.	Extreme Height, m.	Spread, m.
2/3	9	86.7	2.99	3.29
10/2	13	84.5	3.08	3.26
12/2	11	71.3	3.04	3.14
5/1	7	69.8	2.74	3.09
1/1	9	68.5	2.74	2.90
12/3	10	68.1	2.76	2.93
12/5	10	67.5	2.74	3.12
5/3	10	65.8	2.77	3.20
1/2	8	65.0	2.69	3.05
5/5	12	57.0	2.71	2.99

The brackets in column 3 show the result of a statistical examination of the data for stem size. The larger differences, between 2/3 and 10/2 on the one hand, and 5/3, 1/2, and 5/5 on the other, are almost certainly significant; in other words, 2/3 and 10/2 may be expected, at least in soils similar to that at East Malling, to produce Morello trees with large stems, whilst 5/3, 1/2, and 5/5 may be expected to give trees with small stems.

The measurements of height and spread largely confirm those of stem size; but there are one or two curious discrepancies. The trees on 5/3, for instance, have heads of exceptionally wide spread in proportion to their stem size; they are also considerably taller than would be expected. Younger trees of Kentish Red in some measure confirm this result, since in comparison with trees on other sweet cherry stocks those on 5/3 come higher in the list in height and spread than they do in stem size. The trees on 1/1 and 12/3, also, are considerably smaller in spread than would be expected, though their height is about proportional to their stem size. Two or three years' further records, especially of those from the trial with sweet cherry scions, will perhaps show whether this is due to rootstock influence or to some other factor.

The results with other scion varieties, up to the present, confirm in large measure the differences shown in Table I. Thus (whilst 1/2, 2/3 and 10/2 have not yet been worked with scions other than Morello), 12/2 is usually giving trees above the average in vigour, and 12/5, 5/3 and 5/5 somewhat below the average.

There are indications that, as regards vigour, certain scion varieties may have special stock preferences, as occurs amongst apples and other fruits; but

several years' further observations will be required before this point can be cleared up.

(b) *Habit.*

Whilst the Morello is by nature of a spreading habit of growth, some trees become considerably more spreading than others. Vigorous trees tend, at least in their early years, to produce more branches of somewhat erect growth, and less very drooping, than those of less vigour. Since the rootstock seems to have influenced the vigour of the scion, it might therefore be expected to influence its habit also. This is found to be the case. The most striking differences, between trees on Mahaleb stocks and on certain sweet cherry stocks, will be described later. Similar, though less obvious, differences occur amongst the trees on different sweet cherry stocks.

For example, the vigorous trees on 12/4, in the second series, are quite clearly more upright than the neighbouring rather weak trees on 5/2 and 5/4. Further examples may be seen in Table I. Whilst the spread of the trees is in all cases greater than their height, the average difference varies from ten centimetres in the case of the trees on 12/2 to forty-three centimetres for the trees on 5/3; in other words, the spread is greater than the height by from 3 per cent. to 15 per cent.

It is natural to suppose that the weight of fruit borne by the trees may have influenced their shape. Reference to Table II will show that, whilst this may explain the widely spreading habit of the trees on 5/3, it will not explain certain other differences. The trees on 10/2 and 12/2, for instance, have in three years out of four up to the time of the last measurement (1932), borne considerably more fruit than the at least equally large trees on 2/3, yet the former are distinctly less spreading than the latter.

It seems very probable that different sweet cherry rootstocks may produce measurable differences in tree habit, apart from their possible influences on cropping; but up to the present these differences do not seem likely to become of much practical importance.

The word "habit" may perhaps be used to cover peculiarities of growth other than shape of tree and pose of branches. It was noticed in 1926 and later that the trees in the second series on the sweet cherry stock 5/4 were much more open-headed and had less interior wood growth than the comparable trees on other sweet cherry stocks, 5/2 and 12/4. Unfortunately it has never been possible to obtain a photograph showing the difference; but it is reflected in the number and weight of shoots and branches removed in pruning. Since the pruning has been directed chiefly towards keeping the heads of the trees open, it has resulted in the cutting away of more wood from dense than from open trees.

The trees on $5/4$ are most nearly comparable in size with their neighbours on $5/2$; the former are slightly the larger, on the average, in height, spread, and stem size. Yet in the six years from 1926 to 1931, inclusive, the prunings removed from the trees on $5/4$ averaged 54 per tree per year, weighing 1.85 lbs.; whilst those from the trees on $5/2$ averaged 73 per tree per year, weighing 2.27 lbs.

Since the Morello is mainly dependent for fruit-bearing on abundant annual shoot growth, such a rootstock influence as this might be expected to affect cropping adversely. In the present instance this expectation has not been borne out, as will be seen in the next section.

(c) *Cropping.*

Morello cherries usually produce blossoms freely whilst very young; even in the second year from the bud there is usually much blossom, unless it is cut away in pruning. But the blossom of the first two or three years seldom produces any considerable amount of fruit; and as no accurate method of recording it has been devised, it has in this trial been largely ignored, as has the later blossom also. Casual observation has not suggested that there have been any striking differences in the amount of blossom *in proportion to tree size* between trees on different sweet cherry stocks.

The crops of fruit obtained from the stock trial trees have been on the whole satisfactory. By their fifth and sixth years from the bud, a few trees were producing as much as 15 lbs. each, and by their seventh and eighth year, the trees on certain stocks averaged from 30 to 40 lbs. per tree. By far the heaviest crop was that of 1931, the tenth and ninth year from the bud of the first and second series respectively. The whole of the trees in these two series (excluding a few very small trees on acid cherry stocks) in that year produced over 75 lbs. of fruit per tree, equivalent to about 10 tons per acre.

The sweet cherry stock varieties represented in the second and third series of trees have not produced large differences in cropping; such differences as there are seem in the main to be directly related to tree size. Since the trees are not so arranged that small differences can be regarded as significant, the results are not presented here. The younger trees of other scion varieties have not yet cropped heavily enough to confirm or contradict these results.

The cropping of the trees on the stocks $5/2$ and $5/4$, referred to in the last section, has been closely similar. In the seven years from 1925 to 1931, inclusive, the trees on $5/2$ cropped the more heavily in 1927, 1930 and 1931, and those on $5/4$ the more heavily in the other four years. The average crop per year has been about $19\frac{1}{2}$ lbs. per tree on $5/2$ and nearly 18½ lbs. per tree on $5/4$. Since the difference was brought about entirely by the considerably heavier crop of the trees on $5/2$ in 1931, it cannot be regarded as significant. The lack of shoot

growth in the heads of the trees on 5/4 has not reduced the crops borne by the trees.

The fourth series of trees, which began to bear fruit in 1929, has given much more definite results in crop weights. Table II gives the average weight of crop per tree, for each year from 1929 to 1933, inclusive, of the trees on each of the ten sweet cherry stock varieties in the series.

TABLE II.
Crop in pounds per tree.
Fourth Series, planted as yearlings end of 1926.

Stock.	No. of Trees.*	1929.	1930.	1931.	1932.	1933.	Five-year total.
2/3	9	1.3	5.9	18.4	18.2	42.8	86.6
10/2	13	2.1	5.7	18.9	22.3	36.2	85.2
12/2	9	2.6	5.5	19.3	21.9	34.3	83.6
5/3	9	1.9	4.8	18.5	17.3	33.3	75.8
12/5	8	1.5	4.0	17.9	17.2	26.9	67.5
12/3	9	1.4	5.0	16.2	22.2	21.7	66.5
1/2	7	1.0	4.1	15.7	15.6	26.8	63.2
1/1	8	1.4	4.3	12.0	20.6	24.3	62.6
5/5	11	1.4	3.6	16.4	10.7	28.3	60.4
5/1	7	0.8	3.5	15.7	12.3	23.6	55.9

* The number of trees shown here is somewhat smaller than in Table I, owing to the death or injury of certain trees from diseases since the last measurements were made.

Column 7 gives the five-year total crop and the result of a statistical examination of the records. Here, as in Table I, no estimate of the effects of soil and position is possible, yet it seems fairly certain that the larger differences are significant. Whilst the small number of trees on 5/1 makes it necessary to regard its exceptionally light cropping with suspicion, this record does not stand alone. Four trees on this stock were included in Series 3; although they grew vigorously, their average crop was considerably lighter than that of the trees on any of the three comparable sweet cherry stocks. Further, it is most improbable that the difference shown in Table II between 2/3 and 5/5 is due mainly to soil or position.

Although 2/3 comes high and 5/5 low in both Tables I and II, the largest trees have not always borne the heaviest crops, or vice versa. Apart from the case of 5/1, just mentioned, which in both the third and fourth series has borne crops unduly light in proportion to tree size, 1/1 comes unexpectedly low in cropping in proportion to tree size; and conversely, 12/5 comes somewhat higher in the list in cropping than in tree height, though not in spread. 5/3, already noted as producing a small stem in proportion to height and spread, has produced crops roughly in proportion to height and spread, and not in proportion to stem size.

On the whole, it seems extremely probable that certain sweet cherry stocks may materially increase or decrease the cropping of the Morello scion, even apart from their influence on tree size.

(d) *Character of Fruit.*

Time of Ripening. Morello cherries are somewhat uneven in ripening, and require picking as a rule at least three times to avoid loss from the marketing of under- or over-ripe fruit. From 1927 onwards, the fruit of the stock trial trees was cleared at three pickings each year, except in 1929 and 1931, when a small quantity was left on many trees for a fourth picking. For the present purpose this fourth picking is reckoned in with the third. Whilst the crop of 1928 was very light, the other five years from 1927 to 1932 provide considerable data to indicate any possible stock influence on the time of ripening.

The earlier pickings are, of course, based entirely on fruit colour. Since a considerable number of pickers has been employed each year, it has not been possible to maintain absolute uniformity in the standard of ripeness at each picking. It is possible that at each of the first two pickings there is a tendency to leave more "ripe" fruit unpicked on large dense trees, and especially on those with a heavy crop in the centre of the tree, than on smaller trees which are easier to reach. But a close watch has been kept on this very point, and wherever a tree has obviously not been picked closely enough, the pickers have been recalled. Such a tendency would clearly not account for any but very small differences in the apparent time of ripening of the fruit.

In the second and third series of trees, the differences in time of ripening (indicated by the percentage of the whole crop gathered at each picking) between trees on different sweet cherry stocks, though consistent from year to year, are not very large. The trees on 2/1 and 12/4 in the second series, and on 12/1 in the third, have consistently ripened their fruit somewhat later than comparable trees on other sweet cherry stocks.

In the fourth series, which began to crop in 1929, the trees on 5/1 have consistently ripened their fruit early, and those on 5/3 consistently late; those on 10/2 were also late, except in 1932, when they were more nearly mid-season. The trees on the other seven stock varieties were inconsistent, having been relatively early and relatively late in different seasons.

In all three series of trees, there seems to be a tendency for trees with a light crop to ripen their fruit early, and those with a heavy crop, late. This will be discussed more fully in a later section.

Size of Fruit. Records have been taken each year, either of the number of fruits picked from each tree, or of the weight of a random sample of 200 fruits from each tree, at each picking. It is thus possible to trace any rootstock influence on fruit size.

As with other tree fruits, the size of Morello cherries varies to a considerable degree with the extent of the crop in relation to the size of the tree—a heavy crop consisting usually of smaller fruit than a light crop. But it seems probable also that rootstocks may directly influence fruit size, apart from any influence they may have on growth and cropping.

The trees on sweet cherry stocks in the second and third series show consistent differences in fruit size; but these may probably be fully explained by the weight of the crop in proportion to tree size. In the fourth series, however, the trees on the stock variety 12/3 have consistently produced fruit significantly smaller than that of the trees on any other stock in the series. This is shown in Table III.

TABLE III.
Average weight of random samples of 200 fruits.
Fourth Series. 1929-33 inclusive.

Stock Variety.	Number of Trees.	Average weight of sample, lbs.
2/3	9	2.138
10/2	13	2.137
12/2	9	2.069
5/5	11	2.020
5/3	9	1.998
5/1	7	1.993
1/1	8	1.990
1/2	7	1.969
12/5	8	1.963
12/3	9	1.861

The difference has been so striking that it has usually been possible, without any key to the arrangement of the trees on the plot, to pick out the groups of trees on 12/3, on the record sheets, merely by the low weight of the random samples. Although these trees come somewhat higher in the list in crop weight (Table II) than in that of tree spread (Table I), their cropping is actually low in proportion to tree height, and it seems hardly credible that this factor alone could account for the exceptionally small size of their fruit. And even in 1933, when their average crop was nearly 2 lbs. less than that of the trees on any other stock (Table II), their fruit was still the smallest. In all probability another form of stock influence is here concerned.

It is curious to find that the first three stock varieties in this table come each in the same position in Table I, where they were arranged according to area of cross-section of stem. But the fourth in this table, 5/5, came lowest in Table I. Comparison with Table II, where the arrangement is according to crop weight, will again show that the relationship between tree size and crop weight is not the whole explanation of variation in fruit size; special influences of particular rootstocks have almost certainly played a part in it.

(e) *Date of Blossoming.*

Individual tree records, from the fourth series, of the dates of first blossom opening, made for the three years 1929-31, show that the trees on the stock varieties 12/2 and 12/3 have been consistently early in opening their blossoms, whilst those on 5/5 have been consistently late. The average differences are not large, though in certain seasons they may amount to as much as three or four days; and they do not extend to the date when approximately 50 per cent. of the blossoms are open ("full"), and the date when the blossom is over. It seems unlikely that the date of blossoming could be materially advanced or retarded through the use of selected sweet cherry stocks.

(f) *Susceptibility to Diseases.*

Growers of Morello cherries are only too well aware of the injury to their trees and the destruction of crops caused by the Brown-rot fungus, *Sclerotinia cinerea*. Less serious diseases which have attacked certain of the stock trial Morello trees are Silver-leaf, caused by the fungus *Stereum purpureum*, and "Bacterial die-back".

Silver-leaf has appeared to be entirely haphazard in its incidence; there is nothing as yet to indicate that the rootstock influences the susceptibility of the tree.

Until 1933, "Bacterial die-back" also seemed to be entirely haphazard in its incidence. In April 1933, however, a form of "Blossom wilt", probably caused by bacteria, and quite distinct from the well-known blossom wilt caused by the Brown-rot fungus, made its appearance, and revealed a marked rootstock influence on the susceptibility of the trees. It has not yet been possible to determine the relationship, if any, between the bacteria found in wilted blossoms and those known to cause "die-back"; it seems quite possible, however, that they may be identical.

The disease was most severe amongst the Morellos of the fourth series. Two independent estimates were made of the percentage of blossoms killed on each tree: whilst one estimate was somewhat higher throughout than the other, both placed the trees on the various rootstocks in the same order. The differences were large enough to make it very unlikely that soil or position materially influenced the result. Thus, whilst the most severely attacked trees were those on 12/3 with 30 per cent. and on 10/2 with 26 per cent. of their blossoms killed, at the other end of the scale the trees on 5/3 and 1/2 each had 9½ per cent. killed, and those on 2/3 only 6·7 per cent.

Whilst these apparent differences in susceptibility may be an indirect result of some other stock influence, it is clear that they are not related to vigour of growth. The least susceptible trees—those on 2/3—and the most susceptible but one—those on 10/2—are the two most vigorous sets of trees in the series.

Brown-rot is very much a seasonal disease, appearing chiefly in years with wet weather at the time of blossoming ; many years' observations are needed to establish the facts. The older stock trial trees were severely affected in 1926 and 1931, and those in the fourth series considerably also in 1932. In other seasons the attack has been slight.

The trees on different sweet cherry stocks in the second and third series showed large and consistent differences in the average number of brown-rot infections per tree in both 1926 and 1931. Since in nearly all cases the larger trees had the larger number of infections, it is uncertain whether the rootstocks influenced their susceptibility.

The fourth series of trees, which made their first year's growth in 1926, were moderately affected by brown-rot in 1931 ; in 1932 the number of infections was larger, though probably less in proportion to number of blossoms. The average number of infections per tree differed considerably between trees on different rootstocks. Thus, in the two years together, seven trees on 5/1 had less than 12 infections per tree ; whilst eleven trees on 12/2, which were considerably taller than those on 5/1 and a trifle larger in spread and stem size (see Table I), had over 22 infections per tree. It is thus probable that different sweet cherry stocks may exert a varying influence on susceptibility to brown-rot.

(ii) MAHALEB STOCKS.

The first and second series of Morello trees each included representatives on two vegetatively raised Mahaleb stocks, 7/1 and 7/2. Whilst the number of trees on each stock was small, the repetition with trees of different ages gives a result of much more value than either series alone.

TABLE IV.
Size and Cropping of Trees on two Mahaleb Stocks.
Measurements at end of 1931.

	No. of Trees.	Area of cross section of stem, sq. cm.	Height, metres.	Spread, metres.	Average crop per year. 1925-31 incl. lbs. per tree.	Average weight of samples of 200 fruits. lbs.
<i>Series 1.</i>						
7/1	3	81	3.15	4.05	20.0	1.92
7/2	3	86	3.15	4.11	16.4	1.80
<i>Series 2.</i>						
7/1	5	88	3.42	4.36	24.0	2.02
7/2	5	86	3.14	4.53	19.5	1.97

Table IV gives the average tree size, crop weight per tree, and weight of 200 fruits, for the trees on the two Mahaleb stocks, up to the end of 1931, the tenth and ninth year from the bud of the two series respectively. In time of blossoming and susceptibility to brown-rot the differences were either negligible or inconsistent from year to year.

In stem size the differences are slight and contradictory; but in spread of tree, both series show the same result. Though the difference in Series 1 was slight, it was large enough to be noticeable on the plot, and in Series 2 it was quite obvious. The greater height of the trees on 7/1 in Series 2 was also very striking.

In both series, also, the trees on 7/1 bore heavier crops of larger fruit than those on 7/2. The difference, though slight in fruit size, was consistent from year to year, and tended to increase towards the end of the period.

No other scion variety has yet been worked on more than one Mahaleb stock variety. It is therefore impossible to say as yet whether and to what extent such differences will be shown by other scions. But we are almost certainly justified in concluding that different Mahaleb stocks will influence the scion differently, just as do different sweet cherry stocks.

(iii) ACID CHERRY STOCKS.

Four trees on each of two acid cherry stock varieties 4/1 and 4/2, were included in Series 3. The number is, of course, too small to give more than an indication of a possible different influence on the scion. Until the trial can be repeated it will not be worth while to say more than that such indications have appeared. The trees on 4/2 are somewhat larger than those on 4/1, but have in four years out of five borne less fruit; the fruit, however, has usually been considerably larger than that of the trees on 4/1. Differences in time of blossoming and susceptibility to brown-rot have been inconsistent.

Considering the immense variation in the collections of acid cherry stocks received from nurserymen, it would be surprising if larger differences than these could not eventually be shown.

C. INFLUENCE OF STOCKS OF DIFFERENT SPECIES.

The relative influence on the scion of stocks belonging to different species of *Prunus* has received more attention in cherry literature than other aspects of the stock question. In most cases where the same scion varieties on different stocks have been studied, the stocks were probably seedlings. Yet in spite of this fact, certain general conclusions have been drawn, and there is even a large measure of agreement amongst the various writers on the subject.

(i) SWEET CHERRY *versus* MAHALEB STOCKS.(a) *Vigour and Tree Size.*

Hedrick (2) gives a very full review of the literature up to 1915, regarding the influence of stocks of different species. In comparing sweet cherry and Mahaleb stocks, he makes the following eight points:—“(1) Trees on Mahaleb are hardier to cold than those on Mazzard stocks.” “(2) There is no question that the Mahaleb is a dwarfing stock.” “(3) . . . most varieties come into bearing earlier on Mahaleb than on Mazzard stocks.” “(4) The size of cherries is the same on trees grown on the two stocks.” “(5) Better unions are made with Mazzard than with Mahaleb.” “(6) The Mahaleb . . . will thrive in a greater diversity of soils than the Mazzard stock.” “(7) . . . it is probable that cherries on Mazzard live longer than on Mahaleb.” “(8) . . . varieties on Mazzard are more productive and profitable than on the Mahaleb stock.”

These points seem to have been based partly on statements in cherry literature, and partly on observations in cherry orchards in the United States and Canada, chiefly in New York State. Since Hedrick's work was published, considerable data on cherry stocks have been accumulated, particularly at Geneva, N.Y. Howe (6), writing in 1927, gives results obtained at Geneva of a comparative trial of seventeen sweet cherry (scion) varieties, fourteen acid cherries, and nine Dukes, on “Mazzard” and Mahaleb. (The stocks are stated to have been seedlings obtained from Europe.) He shows that, up to fourteen years from the bud, “Mazzard” is a more satisfactory stock than Mahaleb for all varieties of cherries. Size, vigour, and longevity of the tree were the only characters notably affected by the stock; though sweet cherries and Dukes mostly blossomed earlier on Mahaleb than on “Mazzard”. After fourteen years, out of 80 trees (2 of each variety) planted on “Mazzard”, 76 were alive and in good condition; whilst of 80 trees planted on Mahaleb, only 37 were alive, and many of these were in poor condition and some nearly dying. Sixteen trees on Mahaleb were as large as comparable trees on “Mazzard”; but nearly half of these were weak and lacking in vigour; whilst all the surviving trees on “Mazzard” were still vigorous.

Philp (7) and Schuster (8) both mention the dwarfing influence of Mahaleb stocks; the former also states that there are cherries on Mahaleb in California known to be over fifty years old, which show no dwarfing influence.

Howe also brings out a point, now well attested, but omitted by Hedrick—the fact that nursery trees are larger and more vigorous on Mahaleb than on sweet cherry stocks. He shows that the dwarfing influence of Mahaleb stocks does not begin to appear until some years after planting.

The East Malling trials fully confirm this statement. Though only two actual plantings of Morello on Mahaleb have been made (in the first and second

series of trees), small lots of Mahaleb stocks have several times been budded with Morello, and observed during their first year's growth. In every case, when yearling trees on any sweet cherry stock were available for comparison, the yearlings on Mahaleb were considerably the larger. Trees of Kentish Red have also fully confirmed this point.

A summary of the available shoot length and stem size records of Morello is given in Table V. For the present purpose, sweet cherry 2/2 is used for comparison with the Mahaleb stocks, since it was the only sweet cherry stock included in both Series 1 and 2. Mahaleb 7/1 is taken to represent the Mahalebs, since 7 1/2 has not so far been worked with any other scion variety than Morello.

TABLE V.
Growth of Trees on Sweet Cherry and Mahaleb Stocks.

	SERIES 1.		SERIES 2.	
	Sweet cherry.	Mahaleb.	Sweet cherry.	Mahaleb.
	2/2	7/1	2/2	7/1
Years from bud.	Total Length of Annual Shoot Growth, cm.			
1	Not measured.		405	897
2	1,310	1,830	314	597
3	727	765	1,649	3,524
4	2,154	2,504	Not measured.	
	Area of Cross Section of Stem, sq. cm.			
3	Not measured.		6.2	11.6
4	9.9	11.5	18.7	27.1
5	24.8	26.1	35.2	45.7
6	39.3	41.7	51.7	60.7
7	57.5	56.8	62.5	71.1
8	67.6	67.1	80.6	87.8
9	85.4	81.2	Not measured.	

Both shoot measurements and stem size clearly show the greater vigour of the trees on Mahaleb in their early years. In Series 1 the trees on sweet cherry stock were already larger in stem size by their seventh year; in Series 2, although they were gaining, they were still behind at the end of their eighth year. In Series 2 the trees on 2/2 probably had the disadvantage of poor soil; trees on two other sweet cherry stocks, 2/1 and 12/4, had by their eighth year produced stems larger than those on Mahaleb 7/1. Actually the trees on Mahaleb were beginning to fall off in rate of growth by their fifth or sixth year. This is confirmed by trees of Kentish Red; those on several of the sweet cherry stock varieties began in their fifth year, for the first time, to increase in stem size more rapidly than those on Mahaleb 7/1; and by the sixth year, only those on sweet cherry 5/2 (noted above as producing small trees) were still behind those on Mahaleb in rate of increase.

In spite of the large trees produced by Mahaleb stocks in the nursery, in the plantation they seem likely eventually to dwarf the tree.

(b) Habit of Growth.

Howe (6) does not mention any difference in habit between his trees on "Mazzard" and Mahaleb. But of his eight plates, each showing trees of the same variety on "Mazzard" and Mahaleb, three (two acid cherries and one Duke) show a distinctly more spreading tree on Mahaleb; and in no case does the tree on Mahaleb appear to be the more upright. The present writer has not been able to find any published reference to such a difference.

In the trial at East Malling, Mahaleb stocks have clearly influenced the habit of the tree; the difference is sometimes so marked as to be obvious at a glance. Plate 1 shows neighbouring trees in Series 1 on sweet cherry 2/2 and Mahaleb 7/2; a still greater difference could have been shown in Series 2, but the trees, unfortunately, are badly placed for photographing. Table VI presents the difference in figures. The widely spreading habit of the trees on Mahaleb in Series 1 is well shown by the proportion of height to spread. In Series 2, however, the trees on sweet cherry 2/2 appear, as shown in Table V, to be unduly weak, and they are more spreading than normally; figures for the trees on three other sweet cherry stocks are therefore given for comparison.

TABLE VI.
Habit of Trees on Sweet Cherry and Mahaleb Stocks.

			Height metres.	Spread metres.	Proportion Height : Spread.
			SERIES 1.	End of ninth year from bud.	1 :
Sweet Cherry	2/2	..	3·37	4·16	1·234
Mahaleb	7/1	..	3·15	4·05	1·286
"	7/2	..	3·15	4·11	1·305
			SERIES 2.	End of eighth year from bud.	
Sweet Cherry	1/1	..	3·30	4·15	1·257
"	2/1	..	3·42	4·20	1·228
"	2/2	..	3·20	4·10	1·281
"	12/4	..	3·55	4·14	1·166
Mahaleb	7/1	..	3·42	4·36	1·275
"	7/2	..	3·14	4·53	1·444

It is clear that these two Mahaleb stocks, especially 7/2, have a tendency to make the Morello tree more spreading than it is on most sweet cherry stocks. Earlier measurements show that, up to the third or fourth year from the bud, the trees on Mahaleb were not the more spreading; the change in habit seems to begin roughly at the time when the trees on Mahaleb fall off in relative rate of growth. Owing to the overcrowding of the plantation, involving the trimming up of many of the trees (particularly those on Mahaleb) measurements of spread were not continued beyond those given in the table. Eye judgment, however, suggests that the wide spreading habit of the trees on Mahaleb tends to increase.

The trees of Kentish Red on Mahaleb 7/1 fully confirm the change in habit shown by the Morellos. Here the wider spread was already indicated by measurements at the end of the third year: three years later it had become much more striking.

From about the sixth year onwards it has been repeatedly noticed that the one-year-old wood shoots of Morello trees on Mahaleb are more slender than those of other trees. Measurements of the diameter of ten shoots of each tree on Mahalebs 7/1 and 7/2, and on sweet cherry 12/4 (the closest neighbour of the trees on Mahaleb in Series 2), confirmed this observation. The shoots were as nearly as possible of the same length, and were measured at a uniform distance from the tip; they were all terminal shoots, and were as similarly placed on the trees as possible. The result was as follows:—

On sweet cherry 12/4, average diameter 3.46 mm.

„ Mahaleb	7/1	„	„	3.23	„
„	7/2	„	„	3.21	„

This difference is presumably related to the difference in habit; for even if the subsequent secondary thickening of the shoots were equal, which is unlikely, the shoots of the trees on Mahaleb would still be the more slender, and would be more easily bent down by the weight of fruit and leaves.

(c) *Cropping.*

The crop records up to the tenth and eleventh years from the bud show that, in Series 2, the trees on Mahaleb 7/1 cropped somewhat more heavily than most of those on sweet cherry stocks, except towards the end of the period. In the case of the few trees in Series 1, however, this relationship was reversed; the result therefore cannot be regarded as significant. As long as the trees on Mahaleb remain larger than those on sweet cherry stocks, however, they will probably bear somewhat more fruit per tree. On the other hand, there are indications that the trees on Mahaleb may sometimes fall off relatively in cropping, even before the trees on sweet cherry stocks have become equal to them in size.

Up to the sixth year, the trees of Kentish Red had borne so little fruit that their relative cropping can hardly be judged. The trees on Mahaleb 7/1 actually bore very slightly more fruit than any of the trees on sweet cherry stocks.

(d) *Character of Fruit.*

Time of Ripening. The available data indicate that Mahaleb 7/2, but not Mahaleb 7/1, may have somewhat hastened the ripening of the fruit, as compared with sweet cherry stocks.

A comparison of the percentage of the crop gathered at each picking (used to indicate "time of ripening"), with the total weight of crop per tree, strongly

suggests that early ripening is associated with light cropping. Such an association is indicated, as shown above, by the crops of the trees in the fourth series ; this is borne out by a comparison of the trees on Mahaleb with those on sweet cherry stocks. The trees on Mahaleb 7/2 have cropped rather lightly for their size, compared with those on most sweet cherry stocks, and those on Mahaleb 7/1 ; and they have been uniformly early in ripening their fruit. It seems probable that, apart from this association, none of the stocks so far tested affects the ripening period appreciably.

Size of Fruit. Whilst the trees on Mahaleb bore, in their early years, slightly larger fruit than most of those on sweet cherry stocks, in 1931 their fruit was distinctly smaller than any other. This tendency, however, was not continued in 1932. It now seems improbable that the range of sweet cherry and Mahaleb stocks included in Series 1 and 2 will give any striking differences in fruit size.

(e) Time of Blossoming.

The trees on both varieties of Mahaleb, in almost every season, have opened their first blossoms somewhat earlier than any comparable trees on sweet cherry stocks. The average difference extends from a few hours in seasons when the blossoms open quickly, to several days in seasons of cold weather at blossoming time ; it does not continue to the periods of full blossoming and petal fall. Unless other Mahaleb varieties should exert a much greater influence on blossoming time, the difference is not likely to be of any practical importance.

(f) Susceptibility to Disease.

The two serious outbreaks of brown-rot, in 1926 and 1931, both indicated that the trees on Mahaleb were more susceptible to the disease than any comparable trees on sweet cherry stocks. Since infection takes place through the blossom, and since large trees usually have far more blossoms than small trees, it is necessary to relate the number of infections to the size of the tree. The shoot growth formed in 1925 was measured, and gives a rough guide to the size of the trees in 1926 ; for 1931, height and spread of tree are the best available data.

The brown-rot infections recorded were those which penetrated right through the pedicel and into the shoot from which the blossoms arose. There were usually many more infections which did not reach this stage ; but it was not found practicable to record them. Table VII summarizes the available data.

In Series 2 sweet cherry stock 12/4 is used for comparison, partly because the trees on this stock were the most nearly comparable in size with those on Mahaleb, but chiefly because they were neighbouring trees in the same row. Position appears to have a great influence on infection by brown-rot ; the trees on other sweet cherry stocks in Series 2, given in Tables V and VI, were in a

different row (outside instead of interior) from those on 12/4, 7/1 and 7/2, and may have had different chances of infection. In 1926 some of them had slightly more infections per unit length of shoots than the trees on Mahaleb (though many less per tree); whilst in 1931 they all had far less infections per tree.

It seems reasonable to conclude that, under strictly comparable conditions, the trees on Mahaleb were more susceptible to brown-rot infection than the trees on sweet cherry stocks.

Cases of silver-leaf and bacterial die-back have been so haphazard that it is impossible to judge whether trees on Mahaleb and sweet cherry stocks differ in their susceptibility to these diseases. The attack of blossom-wilt in 1933, probably caused by bacteria, was too slight in Series 1 and 2 to reveal any stock influence on susceptibility.

TABLE VII.
Susceptibility to Brown-rot.

	1926.		1931.		
	No. of infections per 10 metres 1925 shoots.		Height, metres.	Spread, metres.	No. of infec- tions per tree.
SERIES 1.					
Sweet Cherry	2/2 ..	7.3	3.37	4.16	28
Mahaleb	7/1 ..	12.2	3.15	4.05	41
"	7/2 ..	13.6	3.15	4.11	18
SERIES 2.					
Sweet Cherry	12/4 ..	4.7	3.55	4.14	26
Mahaleb	7/1 ..	8.2	3.42	4.36	50
"	7/2 ..	6.7	3.14	4.53	46

Three neighbouring trees on Mahaleb in Series 1, one on 7/1 and two on 7/2, have been removed on account of an obscure disease or condition with symptoms resembling those of silver-leaf. The trees became weak in growth, and the few shoots they made were very slender; the foliage was scanty, small, and slightly silvery in appearance, though less so than in ordinary cases of infection by *Stereum*. The trees blossomed freely even after the disease was well advanced; but the blossoms were small and had very short pedicels. One tree, removed in August 1931, already showed signs of the disease in 1930; yet it ripened a moderate crop of very tiny fruit in 1931.

The wood of one of the trees was kindly examined by Dr. F. T. Brooks, of the School of Botany, Cambridge, who reported that no trace of infection by *Stereum* could be found.

No other tree of any scion variety on any stock has so far showed these symptoms. The disease or condition appears so far to be peculiar to Morello on Mahaleb stocks.

Howe (6) does not state the cause or causes of the death of trees on Mahaleb stocks in his experiment. But from his brief description of the decrepit condition of many trees, it seems possible that in some cases it may be due to the same cause as necessitated the removal of three trees at East Malling.

Until more trees become affected in the same way, it will not be possible to ascertain whether an organism of some kind is the cause of the trouble. Whatever the cause may be, however, it seems fair to say that, as in Howe's experiment, cherries on Mahaleb are likely to be shorter lived than comparable trees on sweet cherry stocks.

(ii) SWEET CHERRY *versus* ACID CHERRY STOCKS.

(a) *Vigour and Tree Size.*

Hedrick (2) quotes a number of statements to the effect that cherry trees on acid cherry stocks are dwarfed. The present writer has not been able to find any reports of experiments on which the general statement can be based. Philp (7) and Stahl (9), however, both state that the Stockton Morello has a decidedly dwarfing influence, and Philp gives illustrations of trees on this stock, from which it is clear that they are very small for their age. The New Zealand "Kentish" also is known to have a dwarfing influence, though no published statements to this effect have been found. The writer has seen photographs of thirty-year-old sweet cherry trees on "Kentish" in the Harcourt district of Victoria, Australia; the trees appeared to be certainly no larger than ten or twelve-year-old trees on sweet cherry stocks.

TABLE VIII.
Growth of Trees on Sweet and Acid Cherry Stocks.

		SERIES 2.			SERIES 3.	
		Sweet Cherry 1/1, 8 trees.	Acid Cherry Mixed, 6 trees.		Sweet Cherry 1/1, 8 trees.	Acid Cherry 4/1, 4 trees.
Total length of shoots, first 3 years from bud.	cm. }	2,617	1,320		3,615	2,079
Area of Cross Section of stem, sq. cm. }	End of 3rd year 8th year	7.2 84.7	3.7 35.7	End of 2nd year 7th year	2.9 65.8	2.2 40.5
Height, metres	4th year 8th year	1.82 3.30	1.47 2.53	4th year 7th year	2.17 3.02	1.87 2.57
Spread, metres	4th year 8th year	1.88 4.15	1.40 3.23	4th year 7th year	2.03 3.55	1.63 3.12

Philp also records the only instance in cherries of incompatibility between stock and scion of which the present writer knows—the failure of buds of Chapman on Stockton Morello stocks. Grasovsky (10), in a leaflet stated to be compiled from various sources, says that acid cherry stocks do not make a good union, but he omits to say with what scion varieties.

In the East Malling trial, the second and third series of trees each included a few trees on acid cherry stocks. Of six trees in Series 2, one was on the variety 4/1, and five on mixed layers raised from other individuals of the same collection, No. 4. Series 3 included four trees on each of two varieties, 4/1 and 4/2.

One of the outstanding results of the whole trial is the extreme dwarfing influence of these stocks on the Morello scion, compared with the effect of any sweet cherry or Mahaleb stocks so far tried. Table VIII gives a summary of the data on tree size. Sweet cherry stock variety 1/1, the only stock included in both the second and third series, is here used for comparison; as stated above, it produces trees roughly intermediate in size amongst the sweet cherry stocks.

The smaller size of the trees on acid cherry stocks is more striking than might be suggested by the figures for height and spread. Plate II gives a fair idea of the appearance of the trees. The last measurements indicate that the differences shown in the table are increasing from year to year, at least as regards stem size and height. There can be no doubt, in any case, that the acid cherry stocks so far tried have greatly reduced the growth of the Morello scion.

(b) *Cropping.*

The smaller size of the trees on acid cherry stocks is reflected in their very much lighter crops. Table IX gives the average crops in pounds per tree for each year separately.

TABLE IX.

Cropping of Trees on Sweet and Acid Cherry Stocks. Pounds per tree.

Years from bud.	SERIES 2.		SERIES 3.	
	Sweet Cherry 1/1.	Acid Cherry Mixed.	Sweet Cherry 1/1.	Acid Cherry 4/1.
3	Few fruits.	·1	No crop.	
4	·2	·1		1·9
5	9·0	2·2	2·3	·8
6	·9	·3	·9	
7	27·3	9·5	14·9	12·4
8	27·5	8·3	16·5	11·3
9	82·8	13·2	53·2	30·4
Total	147·7	33·7	87·8	56·8

Since all the trees are planted at the same distance, 12 feet, those on acid cherry stocks have produced little fruit in proportion to the space they are allowed. In proportion to actual tree size, of course, the difference would be

smaller. Had all the trees been planted at such a distance that their branches would just have met at the end of the ninth or eighth year, and had the crop per tree remained the same, the crop per unit area from the trees on acid cherry stocks in Series 2 would still have been far behind that of the trees on sweet cherry 1/1. The same calculation for Series 3 shows that up to the seventh year the trees on acid cherry stocks would have been slightly ahead; in the eighth year, however, they would have been considerably behind. And it is clear that they are still falling further behind each year, and seem likely to continue to do so.

The trees on acid cherry stocks have consistently been lacking in wood shoots; except for a year or two after planting, almost all their wood shoots have been terminal; there being very few lateral wood buds on the trees. It was shown above that such a lack of wood shoots does not necessarily involve reduced cropping; but in the case of these trees, it has probably been a contributory cause.

Although no records of the number of blossoms or blossom buds have been made, it has several times been observed that the "set" of fruit on some of the trees on acid cherry stocks was poor, even in proportion to the amount of blossom, compared with that on trees on other stocks. It is probable that the light crops of the trees on acid cherry stocks are due in part to their small size, in part to their lack of lateral wood shoots, and in part to poor setting of the blossom.

(c) *Character of Fruit.*

Time of Ripening. In view of the suggestion made above, that early ripening is associated with light cropping, it might be expected that the trees on acid cherry stocks would have ripened their fruit very early. In general they have done so, but there are exceptions. Three of the trees on acid cherry stocks in Series 2 have consistently ripened their fruit very early; the other three were similarly early in all but two years, when they were more nearly mid-season. In Series 3, all the trees on acid cherry stock 4/2 have consistently ripened their fruit exceptionally early; but those on 4/1 were early only in 1927, and were mid-season or late in other years. No explanation of these exceptions can be suggested.

Size of Fruit. The exceptionally large fruit borne by some—the lightest cropping—of the trees on acid cherry stocks has been one of the outstanding results of the trial. This has not, however, occurred every year; and the trees in Series 3 have usually borne fruit only slightly larger than that of trees on sweet cherry stocks. In each year from 1927 to 1931, however (in 1928 there were only a few scattered fruits), two neighbouring trees on acid cherry stocks, which have been noteworthy for their very weak growth, produced fruit averaging from 10 to 45 per cent. larger than that of any trees on sweet cherry or Mahaleb stocks. By far the largest fruit ever produced in the trial was borne by these

two trees in 1931 ; their whole crop averaged 2.8 lbs. per 200 fruits, the largest average samples on any comparable sweet cherry stock in the same year being well under 2 lbs. per 200. Nevertheless, such trees, on account of their light cropping, cannot have any but experimental value, save, perhaps, for the production of exhibition fruit, and for garden or pot trees.

(d) *Resistance to Diseases.*

Except in the case of brown-rot, there has been no indication that trees on acid cherry stocks differ in susceptibility to diseases from trees on other stocks.

In both the years of severe brown-rot attacks, 1926 and 1931, the trees on acid cherry stocks appeared to be more susceptible than comparable trees on sweet cherry stocks. In 1926 the trees on acid cherry stocks in Series 2 had from 50 to 100 per cent. more infections per unit length of 1925 shoots than comparable trees on different sweet cherry stocks. In Series 3 the difference was much greater. Eight trees on sweet cherry 1/1 averaged less than one infection per 10 metres of shoots, whilst four trees on acid cherry 4/1 averaged nearly twelve, and four trees on 4/2 over twenty, infections per 10 metres of shoots.

In 1931, the trees on acid cherry stocks all had considerably less infections *per tree* than any others ; but in proportion to the number of blossoms they bore, it was estimated that they actually had many more infections.

It seems likely, then, that trees on sweet cherry stocks will as a rule prove to be somewhat less susceptible to brown-rot than trees on either acid cherry or Mahaleb stocks.

ACKNOWLEDGMENTS.

In conclusion, the writer wishes to express his sincere thanks to many members of the Staff at East Malling, who have been concerned in propagating the trees, pruning, and recording. In particular, he would like to thank Mr. T. N. Hoblyn, who made the statistical examination of the records of which the result is given in Tables I to III.

SUMMARY.

This report discusses cherry stocks of three species : sweet cherry, Mahaleb, and acid cherry ; their vegetative propagation ; the variation amongst seedlings ; and their influence on the Morello scion.

It has been found possible to propagate any species of cherry stock vegetatively, by one method or another.

Seedling stocks of all three species were found to vary considerably, especially those of acid cherry.

Selected sweet cherry stocks, propagated vegetatively, were found to produce measurable differences in the Morello scion, in vigour of growth, weight of crop, and character of fruit.

There are indications that different Mahaleb stocks, and different acid cherry stocks, will produce similar differences.

As compared with sweet cherry stocks, Mahaleb produced larger trees in the nursery, and at first in the plantation. Later, the trees on Mahaleb became weaker, and more spreading in habit; their cropping and fruit character were not much affected. They were more susceptible to brown-rot, and will probably be shorter lived.

Trees on acid cherry stocks were much dwarfed. Their crops were light, though in some cases fair in proportion to tree size. Some of them bore by far the largest fruit produced in the trial. They were probably more susceptible to brown-rot than trees on sweet cherry stocks.

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PLATE I.



Morello on Sweet Cherry and Mahaleb.
Note spreading habit on Mahaleb.



On Mahaleb 7/2.
(Tree on Mahaleb 7/1 beyond.)

On Sweet Cherry 2/2.
(Small trees on Acid Cherry Stocks beyond.)

PLATE II.



Morellos on Acid Cherry Stocks.
(Same scale as Plate I.)

"FREE" OR SEEDLING ROOTSTOCKS IN USE FOR PEARS:

THEIR DESCRIPTION, SELECTION, VEGETATIVE PROPAGATION AND PRELIMINARY TESTING

By R. G. HATTON

HORTICULTURAL tradition regarded the rootstocks in use for pears—the "Quince" and "Free" stocks—as closely analogous to the "Paradise" and "Crab" used for apples. Whilst the "Quince" corresponded with the "Paradise" in inducing dwarfing habit and early fruiting, being a widely different species it was recognized as not infrequently incompatible to certain cultivated varieties of pear, which must therefore either be "double worked" over Quince or worked directly on to Free Pear stock.

The description, standardization and preliminary testing of most of the forms of Quince hitherto in common use has already been dealt with in two reports (1 and 2). Parallel with this work, but necessarily much slower to yield results, has been the examination, description, selection, vegetative propagation and preliminary testing of the "Free" or Seedling Pear stocks.

These experiments in selection and propagation were reported on from time to time in the Station's Annual Reports. In 1922 the wide variation in the seedling collections was reported (3); in 1923 it was stated that layers of many of the selections were transplanting as well as apple stocks (4), though by 1931 this statement was somewhat modified (5). In 1924 the first set of pears worked upon vegetatively raised pear stocks became available, and even in the maiden year "startling differences in the suitability of these selections" were suggested (6). In 1926 and 1927 several of the layered pear selections were said to be definitely unsuitable as stocks (7 and 8). As a result of the successive nursery trials it was reported in 1928 that it had been possible to discard certain races with confidence and to multiply others more rapidly. Significant differences were then beginning to appear in the young plantations (9). By 1932 the first crops and the marked differences between trees on the various stocks were reported (10). This led to the present exhaustive examination of the records.

GENERAL TECHNIQUE.

When, as in the present case, the investigator is faced with an entirely unexplored yet endless supply of seedlings from which to select representatives and test them for their rootstock performance, the apparent hopelessness of the project is at first likely to impress him. However, experience in handling the

problem with seedling stocks for plums and peaches (such as the Myrobolans, St. Juliens, etc.), cherries (such as the Geans or Mazzards, Mahalebs or Austeras) and pears, as in the investigation about to be described, has evolved a more or less common "strategy". This logical or organized sequence of stages in such trials may well be summarized here, since it serves as a guide in seeing how closely inter-related one section of this paper is with another; and it also sets out clearly for the first time the methods being applied every day at East Malling in sifting out the thousands of new seedling rootstocks, which it has either collected from far and wide or deliberately raised from controlled crossings in its search for the best possible combinations of characters in the rootstock. Indeed, this organized procedure has, as a result of the accumulation of endless small bits of experience, been found so widely applicable that it has become with appropriate adaptations more or less the routine in starting to handle any horticultural material.

(1) *Collection*. First there is the spreading of the net sufficiently wide to secure a fair representative sample of the material as handled and accepted commercially.

(2) *Description and Classification*. Secondly there follows a period of close observation of the material, with the description of its botanical and pomological characteristics. Upon either or both of these are based its classification into types or groups, apparently different, according to leaf, growth or root characters, etc.

(3) *Selection*. Since it becomes impossible to test all the individuals classified as belonging to any one group or type, it becomes necessary to select representatives of these groups, which sufficiently represent the range of difference within any one group. This selection will probably embrace both botanical characters such as leaf, bud and wood characters, and also pomological ones such as vigour and health, and type of root system.

(4) *Propagation*. To some extent selection is ultimately dependent upon the possibility of propagating the individual vegetatively, so that a clonal race may be established. The choice is, of course, limited by the possibility of reproduction by these methods and guided still further by the indications of ease of propagation which these tests reveal. Each individual is "stooled" or "layered", earthed up and finally uncovered in order that the extent of the rooting on young shoots and the numbers produced may act as a guide. However desirable a rootstock may be, it is ultimately of no practical value unless it can pass the test of the layer bed and be raised economically.

(5) *Trial*. (a) In the nursery; (b) in the plantation.

These phases only become possible and desirable upon those plants which have passed the propagation test.

(a) The trial in the nursery has become more and more important as data over a period of years have accumulated and demonstrated that certain deductions

can be drawn from nursery trees, which are subsequently corroborated and developed in the field.

Questions of response to transplanting, ease of budding and of congeniality to particular scion varieties initially arise. The amount, vigour and type of growth of the one-, two- and sometimes even three-year-old trees, and the number and position of axillary fruit buds borne are always recorded; and have been proved to give good preliminary indications upon which to base further selections and discardings. Exigencies of space, and the rapid multiplication and repetition of trials, have greatly added to the importance of these trials in the nursery which are now randomized as any field trial would be.

(b) In the plantation. The material which shows promise in the nursery or evinces some new characteristic as a result of the combination of stock and scion, is finally transplanted into permanent position in the field where various expressions of growth, blossoming, fruiting, etc., are recorded annually during the life of the tree, and reported on as different stages in the tree's life appear to warrant. The first stages of the pear stock trials at East Malling have now been fulfilled and the plantation test is now sufficiently advanced to give some indication of the influence of rootstock upon scion. It has therefore been decided to report on the investigations to date.

THE MATERIAL.

Between 1917 and 1921 some ten collections of seedling pear rootstocks (mostly 6-10 mm. grade), variously named "Free", "Seedling" and "Wild" pear, were procured and planted for individual examination. Some came from three different French sources as "Free" and "Seedling" pear, and the fact that these all contained an occasional apple seedling suggested that their origin was probably from the cider or perry press. Others came from Luxemburg as "Free" pear, whilst a collection from a well-known firm of tree nurserymen in the North of England came as "Wild" pear. Five smaller samples (varying from 45 to 100 individuals) from Professor Sprenger, Wageningen, Holland, were understood to be from open pollinated fruits of the varieties St. Nicholaas, Bergamotte, P. Huig, Kleipeer, and Groenpeer.

In all, about 2,500 individuals from these seven sources were originally planted for examination, but in nearly every case the mortality of these pear seedlings was high, and detailed records of only about half the total are available.

Finally, in 1928 a further 500 seedling pears were obtained from France with the object of ascertaining the percentage which would show signs of adventitious rooting, and further to test the possibilities of grading or classifying seedling pear stocks from the root and shoot characters of the young plants, in order to obtain a greater uniformity of behaviour in the worked trees.

THE METHODS OF SELECTION.

(a) BOTANICAL DESCRIPTION.

The methods of examination and selection from these collections have been threefold. First, the individuals in the collection were recorded for their foliage, wood growth and root characters. Secondly, each individual was subjected to a propagation test—i.e. it was cut to the ground-level and "stooled". If the individual showed any signs of adventitious rooting by this method, its shoots were layered in subsequent years and clonal races established by the etiolation method (13). Finally, an attempt was made to select different root types.

The two processes of description and propagation were, as far as possible, carried on simultaneously, in order to save time and in the hope that it would be possible to find individuals capable of more or less ready vegetative propagation, and which would represent the whole range of botanical and morphological characters in these collections.

In carrying out the descriptive work, it soon became obvious that most of the collections comprised at least four more or less distinct types of seedling pear, which almost suggested that at least three or four of the different species mentioned by Decaisne* (14) were involved, as in the case of the origin of named varieties of pear. Each of these types, labelled for convenience sake A, B, C and D, had strong, medium and weak growing individuals—some showing signs of adventitious rooting, others none at all. Between these very distinct types there were numerous intermediates and occasionally an individual which appeared to be altogether a "break away" from any of the main groups, so at one period further groups, such as E, were added. Eventually these were judged not to be sufficiently important, representative or distinctive, and they were abandoned.

Several rather suggestive facts emerge from an analysis of the number or proportion of plants in the collections from certain different sources. The following are the approximate numbers placed in each group:—

TABLE I.

Collection.	Name.	Source.	Total No. of Plants.	No. in Group.				
				A.	B.	C.	D.	Unplaced.
1	Free pear	France	72	26	13	15	8	10
3	Seedling pear	France	348	125	54	102	42	25
4	Seedling pear	France	399	129	99	94	58	19
5	Free pear	Luxembourg	165	35	69	32	14	15
2	Wild pear	England	100	12	absent	60	24	4

* The writer is indebted to Mr. E. A. Bunyard for referring him to this reference.

Whilst the A and C groups seemed to predominate in all the French collections, though they came from distinct sources, B and D types were also present in smaller quantities. In the collection from Luxemburg the B group predominates whilst A, C and D types are also recognizable. The "Wild" pear from North England was characterized as mainly C group, with fewer A and D (the proportion being 5 : 1 : 2) whilst the B type seemed altogether absent. The five Dutch collections did not fall exactly into any of the established groups, though they approximated most nearly to Group D. They all bore a very distinct family resemblance which was, for convenience sake, called the "St. Nicholaas type"—though these split up pretty obviously in each collection into "broad" and "lanceolate" leaved individuals.

Before discussing the possible significance of these proportions, it is necessary to describe the chief characteristics of each group.

Very detailed descriptions have been made on the annual growths from the "stools" along the following lines, during the growing season.

i. *Habit of Growth.*

Growth (strength and sturdiness, and number).

Branching (spines or feathers).

ii. *Wood.*

Colour, hairiness, texture.

iii. *Lenticels.*

Number, shape, colour, conspicuousness.

iv. *Leaves.**

Size, shape, length, breadth, base, apex, serration, surface, pose in relation to stem, colour (above and below), hairiness (above and below).

v. *Leaf Stalk.*

Shape, length, colour.

vi. *Stipules.*

Size, margins, shape.

These descriptions have been checked on numerous occasions over a period of years since August 1921, and although slight variations in wood colour or "spininess" occur as a result of seasonal and cultural conditions, sufficient characters have been found at once both sufficiently constant and distinct, to make it readily possible to define a group and pick out typical representatives. That any person is certain to find intermediates that might belong to either of two groups is certain, but at this stage in the investigation this does not appear to be a matter of great practical importance. It is, therefore, not proposed

* Spur leaves are excluded.

(except in the case of the four group type plants of which full descriptions are given as an appendix) to publish the full detailed descriptions which exist of the seventeen representative clonal rootstocks, which resulted from this method of botanical classification, or of the many other selections already discarded or still undergoing nursery trial, but only to tabulate the most characteristic features whereby the seventeen may be recognized. This method will also illustrate the range of individual plants which have been designated as representatives of any one group. Undoubtedly by multiplying the groups—as was originally initiated—any one grouping would have been less open to criticism botanically but far less welcome pomologically.

The summer characters by which the four groups can be readily distinguished are as follows :—

Group A. The chief characteristics of this group are the ovate to oblong leaves, upfolded from the midrib. The apex of the leaf is usually acute to abruptly acuminate. The petiole is almost horizontal to the stem but the leaves often droop very considerably towards the apex. The wood is usually of a light reddish brown to purple colour—sometimes pubescent—(see leaf details, Fig. 1, and summer shoot, Fig. 2). Decaisne's *Pirus communis* and *Pirus oblongus* might here be represented.

Group B. The leaves are ovate to elliptical. The surface is flat, the margins sometimes even being slightly downturned. The apex of the leaf is acute to acuminate. The petiole is usually upturned, the leaf tending to take the same pose in relation to the stem. The wood is greenish to deep brown and is exceedingly pubescent. The leaves being also very hairy on both upper and lower surfaces, the whole shoot presents a mealy appearance (see leaf details, Fig. 1, and summer shoot, Fig. 2). Decaisne's *Pirus nivalis* is at once suggested.

Group C. The leaves are broadly ovate to circular. The surface is usually flat to slightly upturned, the margins often being considerably “ wavy ” and the serrations somewhat coarse. The petiole is usually held horizontally or slightly upturned, the lamina showing a similar pose in relation to the stem, sometimes drooping slightly towards their apex, which varies from being acute in some representatives to gradually acuminate in others. The wood is usually very dark purple brown, slightly pubescent, almost invariably with a considerable number of short stiff spines (see leaf details, Fig. 1, and summer shoot, Fig. 2). The descriptions of Decaisne's *Pirus cordata* would well fit this group.

Group D. This group appears to be distinguished from Group A by the fact that the leaves are oblong lanceolate with the apex very gradually acuminate. The base of the leaf, instead of being rounded as in the other three groups, is characteristically “ narrowing ”. Whilst the leaves are upturned at the margins they are not so completely upfolded. Though the petiole is usually horizontal

to the stem, the pose of the leaf is distinctly irregular, varying from erect to horizontal, slightly drooping at the apex. The wood varies from light purple to brown purple (see leaf details, Fig. 1, and summer shoot, Fig. 2). The leaf forms of *Pirus syriaca* as figured by Decaisne are somewhat closely resembled in this group.

It may, then, not be a mere matter of chance that in the Wild Pear seedlings of this country, Group C—the *communis* and *cordata* types are found to predominate, and that the woolly leaved Group B is absent. The woolly leaved pears which are cultivated most in certain parts of the continent are generally not considered of high quality and probably have not been widely introduced outside particular areas.

From France, where the pear has been experimented with for so long in all its forms, the more heterogeneous collections of seedlings were only to be expected.

In 1923-4, and again in 1930-1, series of twenty or fifty "typical" leaves—seventh, tenth and twelfth leaves from the apex—were collected from one-year growths and even established bushes, in order to measure their greatest breadth, length of lamina and petiole. The object was to investigate whether it would be possible to establish some very definite relationship in each group between length and breadth of leaves. Although over 6,000 individual measurements were made, the means arrived at merely proved a useful supplement to the

TABLE II.

Mean measurements of twenty tenth leaves in millimetres.

	Max. Breadth of Lamina.	Max. Length of Lamina.†	Ratio of Breadth to Length.	Petiole.†	Ratio of Petiole to Length.	Total Length of Leaf.
A1	30·7	39·7	·77	11·4	·29	50·1
A3	33·6	50·6	·66	9·0	·18	59·2
B1	31·9	43·5	·73	8·2	·19	51·4
B2	33·5	47·8	·70	13·2	·28	60·4
*C1	32·0	41·7	·77	11·1	·27	52·8
C2	30·7	44·4	·69	7·7	·17	51·8
*C3	36·4	42·6	·85	14·2	·33	56·3
C4	33·9	42·8	·79	14·2	·33	56·6
C7	38·5	46·3	·83	16·5	·36	62·6
C8	42·3	51·5	·82	13·9	·27	64·9
D1	30·9	51·4	·60	12·9	·25	63·9
D3	34·7	55·5	·63	14·3	·26	69·5
D4	30·3	47·9	·63	13·8	·29	61·2

* Ten sets of measurements only available.

† The sum of lamina plus petiole is often greater than total length on account of the overlap of the basal lobes.

Identification Characters in Summer of Clonal Races of Pear Rootstocks, under trial at East Malling.

Group.	No.	Growth and Wood.			Leaves and Petiole.				
		Strength and Sturdiness.	Branching.	Colour and Pubescence.	Shape.	Apex and Base.	Surface.	Serration.	Pose in relation to stem.
A.	1	Medium vigour, somewhat whippy.	Some spines, few feathery.	Reddish brown, much pubescence.	Ovate to oval.	Acute to acuminate, rounded base.	Flat hairy, upfolded along midrib.	Finely serrate.	Petiole and leaf almost horizontal, drooping apex.
	2*	Medium vigour, whippy.	Very spiny and feathered.	Green to pink, some pubescence.	Generally lanceolate.	Abruptly acuminate, rounded base.	Upturned.	Deeply serrate, wavy margins.	Petiole and leaf almost horizontal, apex drooping.
	3	Medium strong, stiff and sturdy.	Some spines and feathery.	Light purple brown, some pubescence.	Oblong ovate.	Very gradually acuminate, rounded base.	Flat, hairless, very upfolded along midrib.	Coarsely serrate, wavy margins.	Petiole horizontal, leaf very drooping to apex.
B.	1	Strong, sturdy.	Many spines.	Deep brown, very much pubescence.	Ovate.	Acute to acuminate, rounded base.	Flat, very hairy, slightly upturned at margins.	Finely serrate.	Leaf erect on upturned petiole.
	2	Strong, sturdy.	Very few spines and feathery.	Green to red brown, very much grey pubescence, "mealy".	Ovate to elliptical.	Acuminate, often abruptly rounded at base.	Flat, very hairy, very slightly upturned.	Somewhat deep serration, wavy margins.	Leaf and petiole upturned.
C.	1	Medium vigour, stiff and sturdy.	Many spines.	Greenish brown to purple, very little pubescence.	Ovate to circular.	Acuminate, rounded at base.	Flattish, hairless, slightly upturned.	Finely serrate.	Petiole and leaf nearly horizontal, apex drooping.
	2	Medium to weak, somewhat whippy.	Many spines, some feathery.	Very dark purple brown, little pubescence.	Ovate to oblong ovate.	Gradually to abruptly acuminate, rounded at base.	Variable, often flat, slightly upturned.	Finely serrate, wavy margins.	Horizontal to downturned.
	3*	Medium vigour, sturdy.	Often spined and feathered.	Dark purple brown, some pubescence.	Oblong ovate to circular.	Acute to acuminate, rounded at base.	Flattish, hairless, slightly upturned at margins.	Finely serrate, wavy margins.	Petiole upturned, leaf horizontal to stem.

C.	4	Strong, sturdy.	Many spines and feathery.	Blackish purple, little pubescence.	Broadly ovate to circular.	Acute to abruptly acuminate, rounded at base.	Flattish, almost hairless, upturned at margins.	Finely serrate.	Petiole and leaf almost horizontal.
	5*	Dwarfish, sturdy.	Much spined and feathered.	Very dark purple brown, very little pubescence.	Ovate to ovate lanceolate.	Gradually acuminate, rounded at base.	Flattish, hairless, upturned.	Coarsely serrate, wavy margins.	Petiole horizontal, leaf drooping.
	6*	Medium vigour, sturdy.	Some spines and feathery.	Green brown to light purple, some pubescence.	Broadly ovate.	Gradually acuminate, rounded at base.	Flattish, hairless, upturned.	Finely serrate, very wavy margins.	Irregular, flattish to upturned.
	7	Somewhat weak, stiff.	Much spined and feathered.	Brown to purple, some pubescence.	Ovate to oblong ovate.	Gradually acuminate, rounded at base.	Almost crinkled, hairless, slightly upturned.	Coarsely serrate, very wavy margins.	Irregular, generally upturned.
	8	Strong, medium sturdy.	Very few spines and feathery.	Greenish yellow to pink, slightly pubescent.	Broadly ovate.	Gradually acuminate, rounded at base.	Shiny, hairless, upturned to upfolded.	Somewhat coarsely serrate, margins wavy.	Petiole upturned, leaf horizontal, apex drooping.
D.	1	Medium vigour, sturdy.	Some spines and feathery.	Dark purple brown, some pubescence.	Oblong lanceolate.	Very gradually acuminate, narrowing at base.	Flattish, hairless, upturned.	Finely serrate.	Irregular, from erect to horizontal, apex drooping.
	2*	Medium vigour, somewhat whippy.	Very many spines, no feathery.	Light purple brown, some pubescence.	Ovate to oblong lanceolate.	Gradually acuminate.	Flattish, almost hairless, mostly upturned.	Finely serrate.	Mostly horizontal.
	3	Strong, whippy.	Many spines, some feathery.	Purple brown, very little pubescence.	Ovate lanceolate.	Gradually acuminate, narrowing at base.	Flattish, hairless, upturned.	Finely serrate.	Mostly horizontal, apex drooping.
	4	Medium vigour, sturdy.	Some spines and feathery.	Green brown to purple, some pubescence.	Oblong lanceolate.	Gradually acuminate, rounded at base.	Slightly upturned.	Finely serrate.	Horizontal to upturned, twisted.
	1	Medium vigour, stiff.	Some spines and feathery.	Dark purple brown, much pubescence.	Ovate to oblong lanceolate.	Very gradually acuminate.	Almost hairless, upturned to upfolded.	Very coarsely serrate. Very wavy margins.	Horizontal, drooping to apex.

* These selections by process of nursery testing have now almost died out as a clonal race.

verbal descriptions of leaves already made, but a few typical ones are worth presenting as confirmatory and supplementary evidence of the wide range of leaf character.

The figures emphasize the characteristics of the D type of leaf—much longer than broad—and of the C group—broadly ovate to almost circular—but, by themselves, do not illustrate the differences between A and B. The relatively long petioles of most of the representatives of the C group also appear characteristic.

Similar measurements of leaves off annual growths of mature specimens of these same rootstock selections very generally show the same tendencies. For instance, whilst the difference between length and breadth of lamina in C4 is only 5.1 mm. that in D1 is 28.8. This greatly exaggerates the difference described in the stool shoots, but the modifications are not always in this direction, and a caution must therefore be given in any attempt to try and identify old plants accurately from the characteristics of their one-year shoots. All the descriptions upon which the classification was made were from the one-year shoots of stools or one-year bedded stocks, both of which arise after more or less severe cutting back.

To-day there are growing in the "museum" side by side eight-year-old specimens of eleven of these clonal selections of pear stock. It is not intended at the present time to publish the descriptions or photographs of these, but in shape and habit of growth, thorniness and branching, leaf and wood colour, they afford quite a dramatic yet typical example of what is meant in commerce by Free Pear stocks. So far only three of the specimens have fruited, one—A1—has borne uniform fruits of medium size, edible, ripening in October, whilst the other two—B1 and C1—have given very small "Bergamotte" shaped pears, green, dotted with russet, very hard, gritty and acid, keeping until February.

A Preliminary Test of the Seedling "Groups".

A few typical seedling rootstocks, representing Groups A, B and C, were reserved (from Collection 3) for budding with Pitmaston Duchess, Emile D'Heyst, Durondeau, and Clapp's Favourite, side by side with the same varieties on a known quince rootstock. It was thought possible that if the classification of pear stocks along the lines of botanical characteristics had any real pomological significance, the trees worked on these seedling groups might give some broad forward indication of outstanding points of difference, even if they evinced lack of uniformity within the group. Further, if individual trees of "good behaviour" appeared amongst them, it was proposed to use such indications as a rapid means of rootstock selection. Root cuttings or suckers would have been taken from any such individuals. Unfortunately the number of trees

ultimately available for planting out on the seedling pear stocks was far too small to permit of any serious statistical comparison. The sets of trees varied from only four up to ten of any one variety on any one group of seedlings. However, there are certain points of interest which appear sufficiently outstanding to deserve mention.

In all cases, the foliage of the trees on seedling pear stock has been a much deeper green colour than on the same variety worked on quince. In the cases of Pitmaston Duchess and Emile D'Heyst the trees on all the Free Pear seedling groups were, according to the record of wood growth to the end of 1926 and of cross section of stem in 1932, nearly twice as vigorous as those on Quinces A and B respectively. In the case of Durondeau, judging from similar expressions of vigour there is very little difference between the trees on Quince B and seedling pear stock, with the exception of a solitary tree on a Pear "C" seedling which is outstandingly vigorous.

The trees on quince have in all cases cropped earlier, more heavily and more consistently than those on any of the seedling root systems.

When comparing the behaviour of the trees on A, B and C seedlings amongst themselves, there is one instance—that of Emile D'Heyst—where the seven trees on C seedlings appear considerably more vigorous than the nine on A or the ten on B, and they also actually set more fruits. Though this is suggestive of a common group character for C type plants, it will be seen later that several of the clonal races of C selections (C3, 4, 5 and 8) were definitely dwarfing. Moreover, the comparable sets of trees on Group B seedlings have been outstandingly variable in growth. Whilst the number of fruits setting in the early years is usually somewhat erratic on any rootstock, these records have been found to yield valuable indications. In examining the fruit record sheets the consistently early fruiting of all the trees on quince, especially in the cases of Durondeau and Emile D'Heyst, is noticeable as compared with the variable behaviour of the trees within any one seedling group. Here there are, in most groups, individual trees which have never fruited at all and others which show consistent signs of early fruiting. It may be possible from amongst these latter, after a few more years of "good behaviour", to select further useful pear rootstocks.

(b) SELECTION THROUGH ROOT CHARACTERS.

The second method of selection attempted was through root and rooting characters. The established root systems of a number of four-year-old plants, as will be shown, offered a considerable range. Since, however, it was found that this root range was fairly well distributed amongst the clonal selections which had already been established for their botanical characters, no further attempt was made to establish separate selections based on root morphology.

(c) SELECTION THROUGH VEGETATIVE PROPAGATION.

The object of this method was to discover and pick out typical individuals amongst the different botanical groups, which could be propagated sufficiently readily by methods of stooling or layering to make practically possible the raising of clonal races of these type plants.

In addition, a special look-out was kept for individuals which showed exceptionally ready rooting.

The majority of the plants in Collections 1, 2 and 5 were cut to ground-level and "stooled" (the young resulting shoots being mounded up with earth) to try and induce adventitious rooting. In Collection 1, out of seventy-two plants so treated, thirteen were noted as showing some sign of rooting from the base of the young shoot. Ultimately seventeen selections, to cover the whole botanical and pomological range, were retained for an improved form of vegetative propagation—layering. Of these, nine are still surviving the nursery test and are being vegetatively multiplied to-day.

Eight plants out of one hundred were selected from Collection 2, but only two of these have propagated sufficiently readily to have survived.

In Collection 5, 223 individuals were "stooled", and though ninety-four of these showed some adventitious rooting on the "collar" of the stock which had been earthed over, only eleven showed any rooting from the young shoots, but, although preserved, not one of these has propagated sufficiently readily for ultimate selection.

Thirty-four selections on botanical and pomological characteristics were made from Collections 3 and 4. Of these, eight showed signs of fairly ready rooting, but only two are still being multiplied vegetatively to-day. Of the five Dutch collections, originally comprising 423 individuals, unfortunately only one representative has propagated easily—a seedling from *P. Huig*.

Finally, one collection of young plants, as already mentioned, was purchased in 1928 and reserved from the first for propagation experiments; and, though some 90 per cent. of the three hundred of these seedlings "stooled" and earthed up for three successive years (1929-31) showed some signs of vegetative propagation, eventually out of nineteen promising individuals only seven were finally reserved for further trial—selected solely on their promising "ready rooting" behaviour in the nursery beds. Thus whilst seedling pear does not appear to respond at all readily to the orthodox methods of "stooling" or even "layering", out of the first four hundred or so individuals handled, thirteen have survived a very rigid nursery test. Five of these root well and two of these "extra" well. Out of the next three hundred individuals tested, seven plants are showing considerable promise. This proved that, at any rate under East Malling conditions, there is no insuperable obstacle to the raising of clonal races of pear stocks. No

special adaptation of methods for the particular requirements of pears has been explored, but there are indications that some of the selections already established would have been at least as successfully reproduced by root cuttings—a method which should afford an ample supply of stocks of which a limited quantity only are required annually.

The manner of rooting of a pear layer usually appears very unpromising and is different from that of the other deciduous fruits previously dealt with. Frequently only a single wiry but much branched rootlet develops in the first year from the etiolated base of the current shoot, but it is surprising on transplanting how rapidly this apparently unbalanced and poor root system develops into a magnificent spreading and deep rooting system, often typical of the original seedling mother of the clone. (See Plate VI.)

The layers of some varieties transplant more readily than those of others, and for practical purposes selections B1, C7, C8, D3 and D4 stand out to-day, after a long nursery test of "the survival of the fittest", as stocks which can be handled sufficiently readily by the propagator to claim that it is now possible to fulfil the somewhat limited demand for clonal pear stocks. Although the layering of pear stocks has hitherto been regarded generally as well-nigh impossible, there are examples on the Continent of Europe of varieties of pear such as the Peiter van Huig being grown locally in Holland on its own roots from suckers.

Fortunately some of the final selections (C7, D3 and C8) are amongst those which have also come through the test of budding and subsequent plantation performance most favourably.

Remembering that these clonal races only began to be reproduced vegetatively from the individual selections in 1920-1, it is extremely interesting to note the very different rates at which they had multiplied by 1927. The following

TABLE III.

	Rooted plants.	Yards layer bed.
A1	126	60
2	39	—
3	—	70
B1	522	110
2	833	260
C1	96	20
2	311	70
3	81	almost died out.
4	934	110
7	505	110
8	483	230
D1	160	70
2	98	—
3	590	160
4	674	90

figures give the approximate number of rooted stocks taken from the original parent layer and its offspring up to that date; and a second column gives the number of "yards run" of layer bed established by the end of 1932.

Whilst the record of the number of rooted shoots on the original stooled parent indicated the probable easy rooting of C₄, 7, 8 and D₃ and 4, C₂ would also have been expected to be readily reproduced, whilst on the other hand B₁ and 2 would have been discarded as of poor rooting promise.

A survey of the nursery records between 1921 and 1927, however, shows that there was both considerable variation in the percentage of rooting of all varieties from year to year, and also within any particular clone from season to season. With a single exception (D₄) in the season of 1921-2 the percentage of shoots rooting never exceeded 30 per cent. and in many cases was as low as 12 per cent. However, in 1923 and again in 1926 very few of the stocks had less than 60 per cent. rooted shoots and some reached as high as 85 and 90 per cent. Even this is not the whole story, for the different years seem to have affected profoundly the number of rooted yearlings which survived transplanting. It is probably roughly true to say that on the average a survival of 50 per cent. of these transplanted layers would so far have to be accounted good—though here it should be recalled that, in the handling of one-year seedlings, a similar loss had often to be faced after transplanting. In 1922 there were, of course, only a very limited number of rooted layers to handle, but reference to the records shows that in practically every clone nearly 100 per cent. survived and did well, whereas in 1932, when the rooted plants within most clones ran into hundreds, the percentage of bedded stocks surviving varies according to variety from 30 per cent. to 68 per cent. The shoots on the layer beds are now much weaker than they were in the early years and there is no doubt that the condition of the layer bed in relation to the output of well rooted transplantable stocks demands careful investigation.

When the original parent seedlings were transplanted for layering, all available cuttings (188 in all) were taken from the roots, so as to increase the clone as rapidly as possible. Though the number and quality of the available roots differed from plant to plant, the fact that 111 grew in itself gave some indication of the possibilities of reproduction from root cuttings. Whilst from some plants it was possible to find up to seventeen suitable root pieces, on others no suitable roots were available. Though in no case was there a complete failure of the root cuttings to grow, the results varied from one growing out of fifteen planted to sixteen out of sixteen.

Further investigations are in progress as to the possibilities of using this method for commercial reproduction.

Before leaving the question of vegetative propagation, something must be said of the original parent roots and of those of their vegetative progeny.

DESCRIPTION OF ROOT SYSTEMS.

An examination and a (somewhat rudimentary) description were made of the root characteristics of many of the original seedling Free Pears, when they were lifted and transplanted at four years old. They had been planted as yearlings in nursery rows at approximately eighteen inches apart in the rows and three feet between the rows. As already stated, the stems had been cut back hard to ground-level and "stooled", and, after three years *in situ*, during which botanical descriptions of the annual shoots and notes on adventitious rooting thereon were made, those plants which had been selected as covering a wide botanical range were dug up and transplanted to form the nucleus of clonal races.

Although the distance betwixt each plant was very small and root competition must have resulted, the occasion afforded a good opportunity for obtaining some idea as to the range of root types. A number of these very distinct types were photographed, and the pictures supplement very effectively the root descriptions, a technique for making which was then only in its infancy.

One thing seemed common to all the root systems examined. There was little or no evidence that the initial radicle or "tap root" had persisted and become an important factor in the system. On the other hand, in one type of root system, well illustrated by Plate IV, fig. 1, practically all the coarse "lateral" roots arose from the base of the stock and continued almost directly downwards. In direct contrast to this were to be found root systems where these basal roots had obviously become subsidiary, and where coarse laterals arising higher up on the "collar" of the stock at first spread outwards and then turned down as in Plate IV, fig. 2. Some individuals had extremely few coarse laterals and tended to send out roots in an almost horizontal direction (see Plate V, fig. 1), whilst others possessed a mass of coarse laterals, branching, yet tending more or less acutely downwards both from the collar and the base of the stock (see Plate V, fig. 2). That the amount, type and distribution of the fibrous roots differed very much from individual to individual is obvious from a comparison of the four types illustrated. Since these individuals were required for replanting, it was impossible to take any accurate weights of "fibre" and different grades of coarse root.

It is not infrequently asked whether, through vegetative propagation, the root characteristics of the seedling parent are not fundamentally altered in the progeny, especially in the direction of depth of rooting. It would not be easy to design an experiment to give an accurate answer to this, but the handling of large numbers of vegetatively raised root systems of many types and ages has convinced the writer that there is at least no relationship betwixt "surface rootingness" and asexual propagation. This is so obvious in some of these clonal races of pear rootstocks that it appears justifiable to present some of the root descriptions which were made at three different times and without reference

Descriptions of Root Systems of Seedling Pear Stocks.

Selection.		Original Seedling, four years.	Four-year-old layer therefrom.	Three-year-old nursery trees.
A1	Type.	Moderately strong, a few coarse roots, a few weak, moderately fibred.	Five coarse laterals, coarse laterals, no fibre, spreading ones well fibred.	Restricted, three to four medium coarse laterals, fair amount of fibre.
	Direction.	Horizontal, towards surface, many directly downwards, fairly deep.	Many, spreading, coarse ones downward and deep.	All coarse roots spread slightly, then directly downwards—deep.
A3	Type.	Strong, very few coarse roots, many small roots, moderately fibred.	Restricted, four moderate laterals at base, many very fine laterals, some fibre.	Five to six long whippy laterals, poorly fibred.
	Direction.	Upper roots spreading, basal roots spreading, then downward, deep.	Fine laterals, spreading, laterals at base downwards.	Rooting mostly horizontal.
B1	Type.	Very strong, very many coarse laterals, very little fibre.	Very vigorous, roots very coarse. Four strong and six medium laterals, all basal, some fibre.	Three to four coarse laterals, practically all from base, intermediate laterals few, not well fibred.
	Direction.	Few horizontal, mostly directly downwards, very deep.	Spreading, then downwards.	Some spreading, then deep. Many roots directly downwards.
B2	Type.	Strong. Strong and moderately coarse laterals, moderately fibred.	Four moderate laterals, finer laterals mass of fibre.	Few coarse laterals from base, five medium laterals, fair amount of fibre.
	Direction.	Downward tendency.	Horizontal.	Horizontal with slight downward tendency.
C2	Type.	Strong, many coarse laterals, few small ones, little fibre.	Seven moderate to fine laterals, long wiry roots, not much fibre.	Five medium to coarse laterals, rooting mostly basal, fairly well fibred.
	Direction.	Spreading with downward tendency, deep.	All downwards.	Slightly spreading then downwards.
C3*	Type.	Strong, many very coarse laterals, branched into finer ones, moderately fibred.	Strong. Five strong basal laterals, six medium coarse ones above, moderately fibred.	Five to six medium coarse and fine laterals mostly from base, practically no fibre.
	Direction.	Partially spreading then downwards.	Spreading then deep.	Spreading then inclined downwards.

* Proved incompatible when worked with Dr. Jules Guyot.

Selection.		Original Seedling, four years.	Four-year-old layer therefrom.	Three-year-old nursery trees.
C4	Type.	Strong, few very coarse but many smaller laterals, moderately fibred.	Weak, many short thin laterals, moderately fibred.	Somewhat restricted, three to four coarse laterals, fair amount of fibre.
	Direction.	Many laterals directly downwards, deep.		Roots deep.
C8	Type.	Restricted, few strong but many fine laterals, moderately fibred.	One very coarse and six medium laterals, moderately fibred.	Few coarse laterals, five to six medium to fine, not confined to base, well fibred.
	Direction.	Partially spreading, then downwards, very deep.	Deep.	Majority spreading and inclined to be surface rooting.
D1	Type.	Moderately strong, many moderately coarse laterals, some fibre on weaker roots.	Seven very coarse laterals, no fibre on coarse roots.	Four coarse and many finer laterals practically all from base, fairly well fibred.
	Direction.	Weaker roots towards surface horizontal, some directly downwards, deep.	Upper roots spreading, basal roots deep.	Spreading moderately deep.
D3	Type.	Somewhat weak, few moderately coarse and some smaller laterals, fibre mostly from main stem.	Seven coarse and many fine laterals, well fibred.	Three to four very coarse laterals from base, fairly well fibred.
	Direction.	Downward tendency, very deep.	Spreading to deep.	Very spreading root system, horizontal tendency, few directly downwards.
D4	Type.	Moderately strong, a few moderately coarse laterals, moderately fibred.	Ten moderately coarse laterals, well fibred.	Five to six medium to very coarse laterals mostly from base, fairly well fibred.
	Direction.	Few horizontal, some directly downwards, deep.	Tendency to go down.	First spreading then directly downwards, deep.

TABLE IV.
Nursery Growth (1924-6 inclusive) of *Dr. Jules Guyot* on Layered Pear Stocks.

Stock.	For all trees.			Trained as standards.			Trained as bush.		
	No.	Weight gm.	Cross section of Stem sq. cm.	No.	Weight gm.	Cross section of Stem sq. cm.	No.	Weight gm.	Cross section of Stem sq. cm.
A1	(16)	434	1.3	(10)	527	1.7	(6)	272	0.9
A2	(22)	142	0.5				not planted	(incompatible)	
A3	(24)	202	1.3	(25)	661	2.0	(24)	292	1.3
B1	(34)	553	1.8				(9)	266	1.1
B2	(24)*	400	1.4				(24)*	400	1.4
C1	(28)	731	3.1	(23)	797	3.3	(5)	431	2.2
C2	(29)	780	2.9	(24)	865	3.2	(5)	380	1.6
C3	(23)	218	1.0				not planted	(incompatible)	
C4	(29)	448	1.7	(10)†	612	2.2	(19)	363	1.5
C5	(11)	397	1.8	(12)			(11)	307	1.8
C6	(23)	865	2.8	(10)†	1,091	3.5	(11)	621	2.1
C7	(21)	795	2.6		1,018	3.2	(11)	539	2.2
C8	(15)	530		(10)†	646	2.5	(5)	391	
D1	(17)	524		(12)	757	2.1	(5)	272	
D2	(16)	712	2.3	(16)	712	2.3			
D3	(32)	740	3.0	(25)	794	3.2	(7)	541	2.3
D4	(29)	913	3.1	(24)	1,015	3.4	(5)	431	1.8
E1	(10)	729	2.3	(10)	729	2.3			

* Three trees suggested incompatibility.

† Two trees failed to grow after heading.

‡ Two trees badly stem cankered.

to one another. There are descriptions, first, of the original seedling parents when dug up at four years old; second, of four-year-old vegetatively raised layers from these originals; and, lastly, descriptions made of the roots of groups of three-year-old Dr. Jules Guyot trees budded on to these clonal rootstocks.

Whilst it is a pity that the method of description is not uniform, and so is difficult of strict comparison, especially in so far as the original parent roots are concerned, the details do seem to bring out quite clearly that certain characteristics, such as the development of downward laterals from the base, or the production of a secondary whorl of less coarse horizontally inclined laterals above, seem often to be retained in the vegetative progeny, as in such cases as A1 and B1. Whilst some of these descriptions of the layers and worked rootstocks appear to resemble remarkably those of the seedling parents—although made quite independently—it cannot be claimed that this is by any means always so (see B2), though if such terms as “coarse”, “deep” and “moderate” could have been replaced by actual weights and measurements there would have been a much more reliable criterion. It is, however, at least patent that these vegetative races of pear rootstocks have not, as a result of their method of reproduction, become by any means uniform in a general tendency to a horizontal rooting habit. For instance, clones B1 and D4 are deeply rooted, whilst B2 and D3 are definitely horizontal and only slightly downward growing. Again, the very distinct types of rooting in the clonal races A1, 2 and 3 are clearly shown in Plate VI, fig. 1 and a different range in clones C6, 2, 5 and 3 shown in Plate VI, fig. 2.

THE BEHAVIOUR OF “DR. JULES GUYOT” ON THE SELECTED CLONAL RACES.

THE NURSERY TRIAL OF THE WORKED STOCKS.

By 1923 there was a sufficiently representative collection of rooted layers to arrange for a preliminary nursery trial. The numbers of each type available were in most cases small, so there could be no grading of the stocks used, nor was there any attempt at carrying out a “randomized” layout. However, the initial results were so unexpectedly dramatic (and were so generally confirmed by two further series in subsequent seasons) that there can be no doubt as to the validity of the major differences and the deductions to be drawn therefrom.

First, Dr. Jules Guyot and later Reine des Poirés* were chosen as the two scion varieties likely to be sensitive to rootstock effect, since they will not readily unite on quince, and are apt to make little or no growth unless worked upon “congenial” rootstocks. In the first trial, the test given was to see if the tree would grow in two years to half-standard height in the nursery, i.e. 4 ft. 6 ins.,

* On a much more limited number of selected rootstocks available.

and if it did to head it back in the nursery row at that level. On those rootstocks which had not given two-year-olds of that height, all the trees were headed back at 2 ft. 3 ins. to see if they would make bush trees. Certain very definite facts were outstanding. After producing maiden trees of Dr. Jules Guyot, selections Nos. A2 and C3 proved incompatible and the trees stood still and ultimately died. Amongst the apparently congenial stocks, although there was some variation within any series on a clonal rootstock, owing probably, as already mentioned, to the use of several grades of each variety of stock, some series obviously made very vigorous growth in their nursery years, others made only medium or weak growth. Though the stronger trees on any one rootstock were formed as half-standards, the weaker ones in the same series were cut bush high—but in several series, namely Nos. A3, B2 and C5, none were fit to form into half-standards, and yet in others, such as A2 and C3, the trees rarely developed much beyond the maiden stage.

The following figures and illustration (Plate VI, fig. 1) are sufficient to show the very wide range in behaviour of Dr. Jules Guyot upon clonal selections of the supposedly compatible strong growing "Free" Pear stock.

In two succeeding years, further series of these clonal pear rootstocks underwent a similar rough nursery test. Unfortunately the numbers and varieties available in successive years were not identical, nor could the arrangement or subsequent formation of the trees (into half-standards or bushes) conform to the first series already detailed. However, the three-year measurements of wood growth in these nurseries show that in the main the stocks which had given vigorous nursery trees in 1925 did the same in 1927 and 1928. Trees of C1, C2, C7, D3 and D4 all appear towards the top of the list, whilst A1, C4, D1, A2, A3 and C3 appear towards the bottom. The most outstanding exceptions are the greater vigour of trees on C8 both in the 1927 and 1928 nurseries, and of trees on B1 and 2 in the 1928 series. Somewhat weak trees were produced on D3 in the second nursery but not so in the third. However, the contrast of considerable vigour at the one end and the dwarfingness and even incompatibility at the other has been so constant in these three successive nurseries that, with a few possible exceptions, which may be due to positional factors or the quality of the one-year layers at planting, it is fairly certain that the performance detailed in the first nursery can be regarded as typical. Although, up to the present, no further material has been available for exhaustive nursery trials, during the years 1928, 1930 and 1931 several of the most representative stocks have been used in the demonstration nurseries, usually thirty of each being budded with Dr. Jules Guyot and the measurements of the maiden trees have been kept. In 1928, maidens on C2 and D4 measured respectively 90 and 86 cm., as against those on B2, A3 and A1 which measured only 77, 74 and 72 cm. respectively. In 1930, C2 again heads the list with a mean growth of 90 cm.,

whilst A3, A1 and B2 averaged 78, 69 and 60 cm. respectively. In that year the trees on D4 measured only 68 cm. of maiden growth. In 1931, C7 was substituted for C2 and the maiden trees thereon averaged 73 cm. of growth whilst those on A3 and A1 made 59 and 54 cm. In this last year C8 was included for the first time and produced even more vigorous trees (92 cm.) than C7. Whilst too much account must not be given to the measurements of one-year trees by themselves, as fairly faithful repetitions of the three preceding three-year-old nurseries they do confirm the observations made therein and so deserve mention.

Surely no more conclusive proof of the range of variability in the influence of seedling rootstock upon the scion need be sought, though it is to some extent paralleled by the experience of Spinks (15) in testing out fifteen Long Ashton clonal selections from seedling apple stocks, amongst which he found a range of vigour comparable with the East Malling "semi-dwarf" No. II to very vigorous (No. XII) groups, and in addition at least one of irregular and very weak performance the behaviour of which approximates to the semi-incompatible pear stocks of these trials.

The nursery trial at East Malling in effect decided the nature of the plantation test which was to follow. In the first place, it effected the elimination of certain rootstocks altogether. It then suggested that certain other rootstocks would never prove very vigorous, and might be useful as stocks for semi-dwarf bush trees for varieties when it was undesirable to use a quince stock. Finally, it gave promise that certain of the selected rootstocks would give vigorous orchard standards even of a comparatively weak growing variety like Dr. Jules Guyot.

A reference to these nursery trials, together with a very striking illustration of bundles of trees showing the comparative vigour of Dr. Jules Guyot on four different selections of these pear stocks, was first given in 1927 (11). A diagram and photograph illustrating the great differences in growth in cm. for the trees on selections C6, C5 and C3, for their three years in the nursery, was published in 1930 (12).

TESTING IN THE PLANTATIONS—BEHAVIOUR OF SIX-YEAR-OLD TREES.

It was therefore decided to plant out both a half-standard and bush plantation of Dr. Jules Guyot using the Reine des Poires trees as pollinators only—and in the bush plantation to include some comparable trees on one or more known varieties of quince. In both these field trials some of the clonal selections of "Free" pear were tested both for bush and half-standard purposes.

The trial of half-standard Dr. Jules Guyot consisting of 165 trees in all, with thirteen different clonal pear stocks, was planted out in March 1927. In addition to these, eighteen half-standard Reine des Poires were interplanted

a year later for pollination purposes. The opportunity was taken at this time to secure the weights and girths of individual trees, given in Table IV, and the description of their root system tabulated on pages 320-21.

The unit of trees planted varied from eight up to sixteen according to the supply available in the nursery. The plot arrangement provided that these units should be distributed as far as possible in four successional blocks over the whole area. Since the number of trees on each stock varied considerably, this method of planting has resulted in a pretty general distribution of each rootstock in different parts of the field.

Table V gives a general summary of the principal observations made with regard to growth characteristics on the series of half-standard Dr. Jules Guyot at six years from transplanting.

TABLE V.

The Comparative Vigour of Dr. Jules Guyot on Vegetative Selections of Seedling Pear Rootstocks.

On Pear Stock.	No. of trees.	Total wood growth in metres.*	Cross section of stem in sq. cm.
C7	(10)	124	27.5
C2	(16)	122	30.9
C6	(10)	119	26.5
C1	(15)	113	26.8
D4	(16)	112	26.8
D3	(15)	99	25.1
D2	(16)	92	20.3
E1	(9)	82	18.5
D1	(10)	77	19.7
B1	(16)	75	16.7
A1	(8)	69	16.8
C8	(10)	66	17.7
C4	(10)	58	15.0

* The trees in this table are arranged in order of their wood growth, those which show no significant difference in this respect being bracketed together. In this and other tables a difference is assumed to be significant, if the odds are greater than twenty to one against such a difference being due to chance.

In the first place the figures demonstrate clearly that within the range of rootstocks, although these were selected as likely to prove vigorous enough for half-standards, there exists a whole significant gradation of growth behaviour. The most vigorous trees (on C7 for instance) are making twice the amount of wood growth as those on C8 and C4. It is, then, interesting to note that although each group was selected, lettered and numbered for its general botanical resemblance, yet including a limited range of variation in growth characteristics within the type, the trees on A, B, C, D and E varieties are not always significantly different from one another. Again, within the fairly comprehensive C series,

although it is suggestive that trees on four of these C rootstock types are amongst the most vigorous, two C rootstock selections have proved the least vigorous. Again, although four series on D type rootstocks come close together in order of growth, yet they actually represent three significantly different growth performances. Any attempt, therefore, to grade seedling pear stocks from botanical characters and to deduce the performance of the trees worked thereon, appears doomed to failure.

The vigour of the rootstocks themselves appears to be an equally uncertain criterion of ultimate performance. Both C2 and 7 are described as weak, whilst B1 and C4 are notoriously strong. Attempts were also made between 1928 and 1931 to grade out pear seedlings in various ways. A number were grouped according to habit of growth, viz. clean of spines and feathers; branched but no spines; and, finally, those plants which were a mass of spines. Another set were divided according to their types of root system into seven series. However, after three years *in situ* the families collected together under any one method of grading were found to contain individuals of all grades of vigour, so that the investigation was pursued no further.

Whilst the column given (in Table V) for cross section of stem appears to bear some general relationship to wood (i.e. total shoot) growth, the apparent exceptions will become more readily explained when studied in relation to fruit bud formation.

Before leaving the question of effect of stock on wood growth, it is worth recording that for purposes of pollination eighteen half-standard trees of Reine des Paires on rootstocks C2 and A1 were interplanted with these trees of Dr. Jules Guyot a year later. They have not yet fruited or blossomed, but the records for their total wood growths and cross sections of stem already show a significant difference in favour of the greater vigour of the trees on C2.

The Reine des Paires on C2 have made 86 metres of growth and the mean cross section of stem is 19.2 sq. cm., whilst the trees on A1 have averaged only 78 metres with a cross section of 15.4 sq. cm.

Table VI gives the total number of fruit buds formed on the tree, and the final count of fruit set. The series are arranged from C7 to C4, as before, in order of vigour, the brackets indicating the significant differences in shoot growth.

Once more within this limited range of supposedly vigorous vegetative selections, fruit bud formation averages 295 on the series on C2 and only 151 on the series on A1, and seedling pear is shown to be very variable. Within the C series alone the trees differ from 295 (on C2) to 168 (on C4).

The second point of interest which emerges is that whilst two series of trees on rootstocks of lesser vigour, D1 and C8, have been prominent in fruit bud formation (226 and 245 respectively), neither have so far set a high proportion

of fruit (5.2 and 3.9 respectively). Again, the series on E1, A1 and C4, which are also low in shoot growth, have proved exceptionally low even in fruit bud formation. This is apparently another example of where comparative "dwarfingness" and precocity in fruit production do not always go together.

TABLE VI.

Showing Fruit Bud Formation in Relation to Total Shoot Growth and Cross Section of Stem.

Trees on Pear Stock.	Cross section of stem in sq. cm.	Total Fruit Buds.	Total No. of fruits per tree.
{ C7	27.5	212	7.9
{ C2	30.9	295	21.0
{ C6	26.5	197	13.7
{ C1	26.8	177	2.5
{ D4	26.8	167	7.6
{ D3	25.1	195	3.3
{ D2	20.3	190	7.0
{ E1	18.5	156	2.6
{ D1	19.7	226	5.2
{ B1	16.7	180	4.0
{ A1	16.8	151	2.1
{ C8	17.7	245	3.9
{ C4	15.0	168	1.7

On the other hand, the three series (trees on C7, C2 and C6) standing at the head of the list for vigour of wood growth are all pre-eminently high in fruit bud formation also, and two (C2 and C6) are exceptional in the number of fruits set. Trees on C1, on the other hand, have been very vigorous and remarkably low in blossom production. It is interesting at this early stage in the trees' histories to find vigour and precocity of bearing not infrequently closely associated, though doubtless as the years pass, the early cropping of these series will react on the ultimate vigour, as has been the case with Nos. IV and VII apple stocks and quince C stock for pears. However, from the economic aspect it would appear to have considerable advantages to be able to build up a vigorous potentially heavy-bearing framework quickly, and then for growth to slow down. It looks as if some of these more vigorous pear stock selections may not only go to illustrate points of scientific interest, but may be of commercial value.

Before leaving the question of fruit bud formation and fruit set, it is worth analysing in more detail the history of each series in 1932, which for all practical purposes was the first year when any quantity of fruit set.

It must be remembered that total fruit buds implies those on terminals, spurs and axillary fruit buds on leading wood growths (which have been subsequently pruned). It is the final count of fruit buds left on the trees after pruning which gives a more real indication as to whether there are any significant

differences, not only in the total number of fruit buds formed, but in the position of such buds: terminal, axillary, or spur. Although the trees are as yet too young to have set much fruit, and the little that has set has been somewhat erratically distributed even within any group of trees on a single rootstock, the details collected in 1932 are given as showing some differences arising from the positions in which the blossoms were formed and the possibilities of a different percentage of that blossom setting upon different rootstocks (as has already been proved to be the case in apples and plums).

In Table VII the series are arranged in the order of the number of fruit buds left on the tree after pruning.

TABLE VII.
Analysis of Fruit Buds and Fruit Set, 1932.

Trees on Pear Stock.	Total Fruit Buds.	No. left on tree.	No. of fruits.
C2	91·6	83·3	17·6
C8	93·8	75·3	3·0
C6	84·9	72·6	12·2
C7	89·3	65·3	7·9
D4	81·4	64·7	7·1
D1	85·9	62·6	3·4
D2	88·2	62·4	5·6
B1	88·9	62·4	3·7
A1	70·2	56·6	2·1
C4	86·6	52·1	1·7
E1	79·2	51·3	1·8
D3	63·3	46·6	1·3
C1	60·1	43·1	1·7

Whilst this table shows a very general relationship between the number of fruit buds left on the tree after pruning and the number of fruits finally set, an actual analysis of the type of fruit bud confirms this still further. Compare, for instance, the series of trees on C2 and C4. Although there was not much difference in the total number of fruit buds counted, there was a striking difference in number left after normal pruning (which had been standardized for all series), and hence in the ultimate set of fruit. In actual fact, 86 per cent. of the total fruit buds on the trees on C2 were spurs—and hence very rarely removed—whilst only 61 per cent. were spurs on those on C4. This difference is statistically significant and partially accounts for the large difference in fruiting.

The table, however, also shows exceptions like C8 and D2 which suggest that other factors such as percentage of blossom setting may also be active. It is also worth recording that from 1929 onwards when the first few fruits were recorded, the figures for trees on the vigorous C2 and C6 were consistently suggestive of early cropping, whilst those on C4, A1 and B1, all in the same category for weaker growth, showed no signs of early fruiting whatever.

Before the question of vigour and fruit bud formation is finally dismissed, it will be well to remember that shoot growth is not the only measure of wood increment. Stoutness of stem as expressed in girth, or better, cross section of stem, is another manifestation of " vigour ". It has previously been pointed out that this latter calculation for each series of trees does not entirely follow the order of total shoot growth; but that the examination of cross section of stem appeared to reveal some relationship between this expression of growth increment and the amount of " fruit bud forming capacity " within the tree. Examination of Table VI shows that in the three most outstanding cases of blossom production, i.e. the series of trees on C2 (vigorous), D1 (moderate) and C8 (dwarfed), the figure for area of the cross section of the stem is abnormally high when compared with members of the other series with which they are bracketed so far as wood growth is concerned. On the other hand, there are two other stocks, D3 and C4, which also show a high cross section to wood growth ratio without a correspondingly high blossom production.

This paper is not the place to pursue further the deductions which might be drawn from this possible relationship. It has also been detected in the examination of other records at the Station. However, it is at least certain that in the light of present knowledge, no one measurement of " vigour " by itself can be relied upon to give a complete picture of wood growth, stoutness, thickening, etc.

For several years some careful observations have been made upon the possible effect of the rootstock on the very varied Autumn colouring of the leaf and of the subsequent defoliation of the tree. In some seasons there appears to be considerable range of leaf colour even in a single series, whilst in 1932 there were indications that certain colourings could be associated with sets of trees on particular roots. There seemed to be some fairly uniform and definite results when in November 1930, estimates of the amount of defoliation were made. At that time some of the trees on the stronger series such as C2, 6 and 7 had only lost from 2 to 10 per cent. of their leaves, whilst those on the weaker A1 and C4 had lost from 50 per cent. to 60 per cent.

In addition to these differences in amount of wood growth and fruit buds which can be measured and counted, there are manifest the usual pomological differences in habit and type of growth and nature of union of the same variety worked upon these clonal selections. In the current year's field notes, for instance, the trees on C2 are described as " very sturdy, square, bushy head - large bold green leaves - stock outgrowing scion at union - well anchored ". Those on A1 are said to be " sparse and whippy in growth, branches rather pendulous, spurs weakish, rootstock outgrowing scion at point of union - well anchored ". Those on B1 are described as " weakish, open and fanlike, leaves inclined to be yellow - spurs weak, stock outgrowing scion at point of union ",

whilst trees on C8 are "medium open, easy to see through, union of stock and scion even, anchorage poor". Some are recorded as suckering at collar, others at some distance from the tree (possibly a sign of surface rooting) and others little or not at all. As years pass, these characteristics generally become accentuated, so it is not proposed at this stage to describe them in greater detail.

The field trial of bush trees of Dr. Jules Guyot upon Angers Quince (A) and another unnamed variety of quince (C1) and some of the less vigorous trees on a range of layered free pear selections was planted out at the same time as the one already described in detail. The units of trees were eight on each variety of quince and (with one exception—five on C8) nine on each variety of pear stock (eighty-four trees in all). The trees on pear stocks included the second grade ones on selections C6, 7, 4 and 8, and B1 already being tested in the half-standard trial, and in addition three other selections, A3, B2 and C5, which in the nursery had not given any trees vigorous enough for half-standard purposes, yet appeared healthy dwarfed trees when transplanted. Records similar to those taken on the more extensive trial are available. In the first place it is most encouraging to find that the trees on C6 and C7, which were headed back as bushes in the nursery because they were the least vigorous in growth in their series and so less suitable for immediate heading as half-standards, have increased rapidly in vigour in their permanent positions and again stand at the head of the list for wood measurements. This is a good instance of the fact that the size of grade of the nursery tree does not mask rootstock influence, in that the character for growth making is relatively maintained. Again, trees on B1 and C8 have behaved similarly to their half-standard brethren in remaining of dwarfish wood growth at the bottom of the list of bush trees.

Of the selections which were never thought vigorous enough to test as half-standards, the trees on B2 and C5 have remained of moderate growth only whilst A3, at the bottom of the list for wood growth, shows signs of a delayed incompatibility, similar to that of Dr. Jules Guyot on the two varieties of quince. On these latter, six out of sixteen trees have already died right out.

Whilst none of the series on pear stocks approach the trees on quince in fruit bud formation, it is again encouraging to find the bush trees on C8 proving exceptional in this respect as were the half-standards in the larger trial. The new selections C5 with nearly twice the wood growth, and A3 with a great deal less, are in the same category. With the exception of the trees on the two varieties of quince—which are now practically at the end of their career—there has been very little fruit set, though trees on C8, 5 and 4 have each set a few.

Throughout the bush trial the trees on C4 have made relatively somewhat more wood growth and shown more propensity to fruit bud formation than when grown as half-standards. The bush trial of Reine des Poires is a year younger

than that of the Dr. Jules Guyot with which the trees are interplanted, and none have as yet blossomed. Although the former variety is budded on to seven Free Pear stock selections (A3, B1 and 2, C1, 3 and 4, and D1), there are only bush Dr. Jules Guyot on A3, B1 and 2, and C4 to compare with these, but it is very encouraging to find that they maintain the same relative order of vigour when worked with either variety. Reine des Poirés on C1 makes vigorous wood growth and on C3 only very moderate growth, whilst those on D1 equal those on B1, all of which facts further confirm the deductions drawn from the half-standard trials. This variety has not succeeded at all on quince.

Until some of these layered pear rootstocks have been worked and compared with other varieties which are compatible both to pear and quince, it is impossible to make a fair comparison between trees worked on both, or to say how far the search which is being made to find selections of pear ready of vegetative propagation, yet producing quick-fruited trees, has really been successful. In both trials the trees had been only six years *in situ* when these records were summarized, the seasons had not been generally very kind to the setting of pear blossom at East Malling, yet even so, trees on such pear selections as C2, C6, C7, and possibly C5 and C8 do not suggest that cropping will be indefinitely delayed as a result of the use of pear roots, despite tradition.

These investigations afford yet one further illustration of the absurdity of generalizing upon the behaviour of trees on seedling rootstocks, either from a practical or an experimental point of view. It has been shown that thousands of these "Free" and "Wild" seedling pears of commerce have been passed under careful scrutiny, have been grouped and graded for their botanical differences and similarities, and apparent growth characters of vigour and dwarfingness. Clonal races representing these botanical and pomological groups and grades have been established and uniformly budded with a single scion variety. In some series, even the union betwixt rootstock and bud proved wholly incompatible, in others it has only been delayed. The remaining series of trees at nine years old have shown that a striking range of growth, blossoming and fruiting performance has become apparent. Experience with other varieties of fruit trees suggests that these differences will be accentuated with time and not "evened up".

There is no predicting how any variety of pear on "Free Pear" will behave at any given date; it is now at least possible to forecast extreme difference in the behaviour of at least one variety on layered pears C2 or C4, although botanically these rootstocks look so much alike.

In conclusion, the writer wishes to acknowledge the indispensable co-operation of Mr. J. Amos throughout these investigations; A. W. Witt's care and enthusiasm have guided the manipulation of the material throughout the nursery experiments. So many of the assistant pomological staff have helped

PLATE I.



Leaf characters of the four Free Pear Rootstock Groups (about half natural size).

A1 (top left)

Br (top right)

C2

D1

PLATE II.



Pose of Leaf in Relation to Stem of Free Pear Rootstock Groups.
Summer shoots of A₁ and B₁.

PLATE III.



Pose of Leaf in Relation to Stem of Free Pear Rootstock Groups.
Summer shoots of C₃ and D₁.

PLATE IV.



FIG. 1.

Range of Root Types. Roots mainly from base and directly downwards (Bt).
Roots mainly spreading then downwards (E).



FIG. 2.

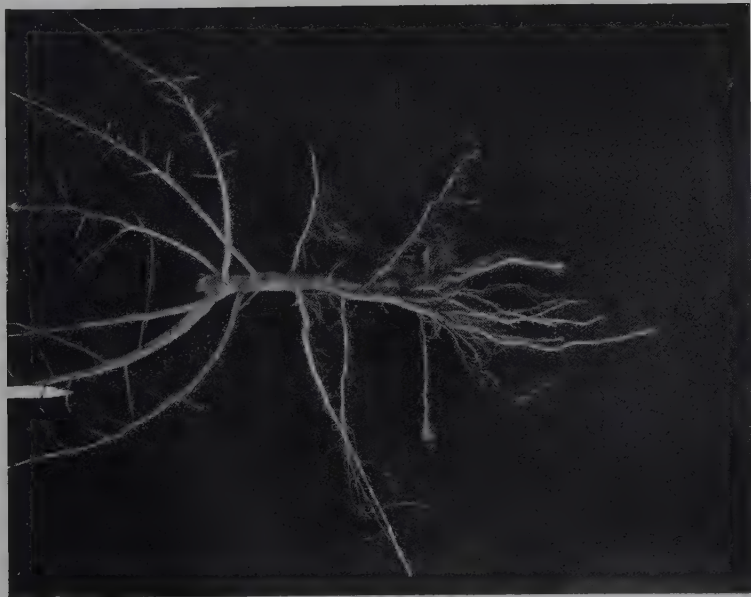


FIG. 1.

Range of Root Types. Few coarse roots—horizontal laterals from collar (A1).
Rooting all up collar—downward tendency—much fibre (D2).



FIG. 2.

PLATE VI.

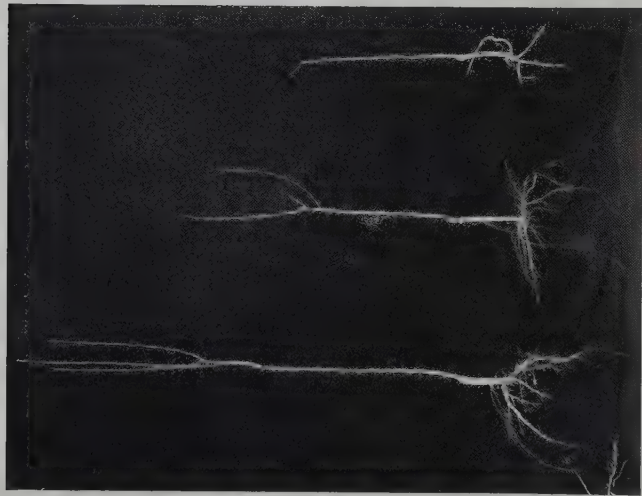


FIG. 1.

Three-year-old Dr. Jules Guyot from nursery, showing typical range of vigour on selections A1, A3, and A2 (incompatible).

Note also different root types.

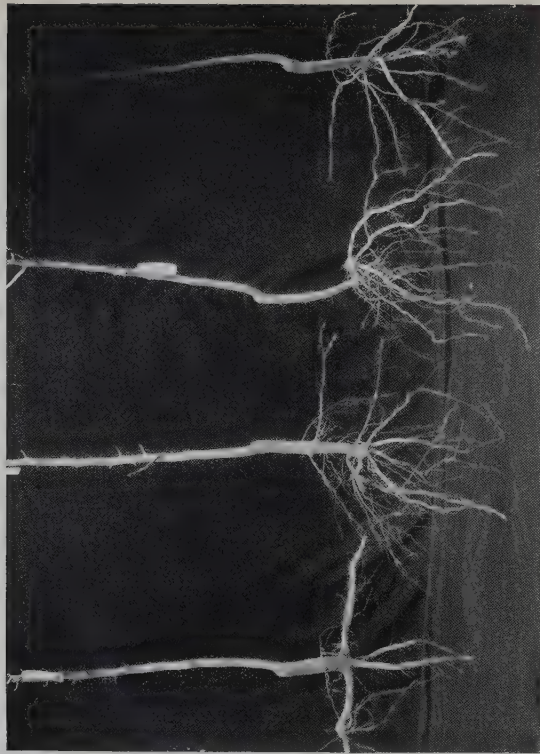


FIG. 2.

Typical three-year-old root system of the vegetatively raised selections (left to right) C6, C2, C5 and C3.

(Compare different habits and note in C6 these 2 roots going directly downwards.)

in recording the routine data and in making observations over the whole period, that it would be invidious to single out any one by name. Mr. T. N. Hoblyn and his assistants have rendered invaluable help in summarizing and evaluating much of the numerical data, whilst Dr. Knight has given helpful suggestions as to the form and presentation of the results.

SUMMARY.

1. Typical samples of the Free Pear rootstocks of Europe were examined, and are botanically described. Four more or less distinct species "groups" (A to D) seemed represented.

2. Representatives of the range of variation within these groups were tested for ease of vegetative propagation and some thirteen clonal races established. Some varieties propagated much more readily than others, which fortunately include some of good pomological performance.

3. The range of root character in the original parents is described and the rooting habit of the plants subsequently raised vegetatively therefrom discussed. Deep rooting clones from layers are quite common.

4. The results in the nursery of budding these clonal selections with Dr. Jules Guyot pear is described. Differences in amount and stoutness of growth of the trees on separate clones were apparent at one, two and three years. Two rootstocks proved incompatible to the variety used after one year.

5. These trees were tested as half-standards and bush trees under plantation conditions. The complete records of their wood growth, cross section of stem, blossoming and fruit bud formation are presented after six years' growth *in situ*. Striking significant differences in vigour are proved, some series making twice the growth of others. Striking differences in early fruit bud formation and type are demonstrated. Early blossoming and dwarfingness have not necessarily been closely correlated.

6. As a result of these experiences it is useless to try and grade seedling pears on botanical characters, the vigour of the stocks themselves or their root type in order to obtain uniformity. Reliance on clonal races, in countries where trees must be stem worked, remains the only method at present.

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BOOK REVIEW

ETHYLENE COLOURING OF CITRUS FRUIT. By H. CLARK POWELL and I. MATHEWS. (University of Pretoria Publication, No. 25, 1933, pp. 20. Reprints, 1s. each.)

In this publication the authors give full particulars of the plant and methods used at the Sundays River Citrus Co-operative Company, Addo, Cape Province, for investigational work on the ethylene colouring of oranges and grapefruit. Certain precautions to be taken in picking, transport and packing are also dealt with.

C.W.

